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INSTRUMENTATION FOR PROPELLER BLADE VIBRATION FLIGHT AND GROUND TESTING

Anthony J. Barile

National Aviation Facilities Experimental Center
Atlantic City, New Jersey

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FINAL REPORT

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16. Abstract

The need for in-flight propeller stress measurements has been evident for the last three decades. This report documents the various instrumentation systems, methods, and techniques particularly suited to this purpose.

The stress measurement process, in general terms, is considered with a more detailed description of the various options available to transmit signals from the propeller to the airframe. The procedures with which the transmitted signals may be recorded, processed, and reduced to meaningful information are presented with an assessment of their relative merits.

An in-depth description of strain gage installation techniques is presented, depicting short- as well as long-term all-weather installations, heretofore uncommon in the state-of-the-art.

Further discussion is addressed to electronic data processing and a typical flight test profile.

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PREFACE

The author wishes to express his appreciation for the cooperation and contributions of Mr. Gilbert Howe, Hartzell Propeller, Incorporated; and Mr. Paul Ruedrich, McCauley Industrial Company. In addition, the author expresses particular appreciation to Marvin J. Walker, whose help and guidance made this work less difficult.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF TABLES

INTRODUCTION

PURPOSE.

The purpose of this report is to document various instrumentation systems, methods, and techniques particularly suited to conducting propeller stress surveys and also to describe their relative merits.

The broad character of the information, as it is presented, is intended to place in perspective, to those unfamiliar with the subject, the nature of the problems involved and their solutions.

BACKGROUND.

The Federal Aviation Administration (FAA) contracted for the research and development of a self-energizing, long-term system that eliminates sliprings. The system uses a constant bandwidth frequency modulation (FM) format and multiplexing of strain gage signals in accordance with Inter-Range Instrumentation Group (IRIG) standards. A capacitive coupling transfers the FM composite signal from the propeller to the recording instrumentation in the aircraft.

Using this method, it becomes possible to do long-term, high-altitude testing with low-bridge voltage under adverse weather conditions ascertaining steady as well as vibratory strain on 16 separate channels. Additional parameters included are altitude, airspeed, vertical acceleration, deck angle, manifold pressure, revolutions per minute (r/min), and a time code. The data gathered are recorded on magnetic tape for further processing through ground-based equipment. A computer program enables a user to rapidly process and analyze this data.

A third system tested by the FAA uses a miniaturized FM transmitter for each channel as a data link from the propeller to the aircraft.

DESCRIPTION OF PROPELLER STRESS MEASUREMENT PROCESS

STRESS/STRAIN MEASUREMENT (SOME GENERAL CONSIDERATIONS).

An increased number of unexplained failures occurred with the advent of metal propellers. This prompted investigations which revealed that the fractures were mainly due to metal fatigue.

Fatigue failure in metal structures is the result of the gradual spread of microscopic cracks or flaws in the metal crystalline structure. These cracks are further propagated by the large number and variety of cyclic bending loads imposed on the structure.

Vibratory stress surveys can be used to eliminate fatigue failure in propellers by applying information gained in such surveys toward better design criteria based on substantial factual test data. Figure 1 likens a propeller to a beam.

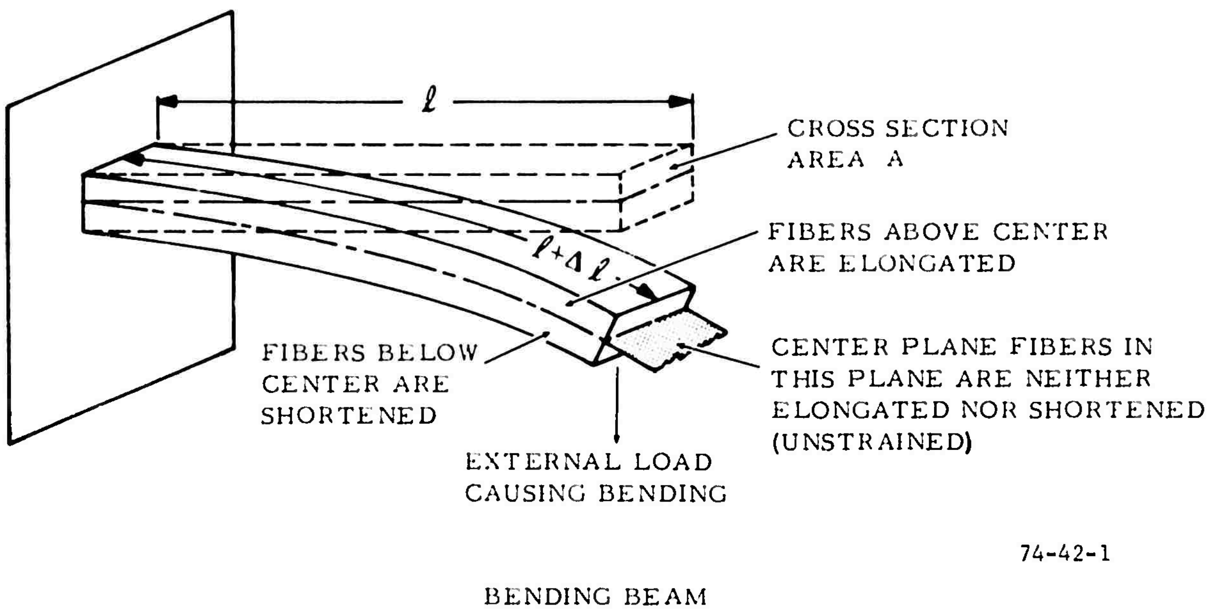

FIGURE 1. BEAM-BENDING STRESS/STRAIN DIAGRAM

When such a structure is bent by an external load, one side will be in tension while the other side is in compression--that is, the compression side is "shortening" while the tension side is "elongating." This compression and tension actually causes a change in the length of each side of the beam and is called "strain." Thus,

Strain = Change in Length Per Unit Length or

$$\varepsilon = \frac{\Delta \ell}{\ell} \tag{1}$$

As the beam is being bent, an opposing force is produced which is resistive to the bending force. This force is called "stress." The stress can be determined by dividing the bending load or force by the cross-sectional area of the beam. Thus,

Stress = Bending Force Divided by Cross-Sectional Area or

$$\text{Stress} = \sigma = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} \tag{2}$$

Stress and strain are related by a numerical constant whose value depends on the material the beam is made from.

This numerical constant is called the "modulus of elasticity" of the material abbreviated as "E." The modulus value of dural, for instance, is 10,000,000 pounds per square inch (lb/in^2).

Hookes law shows the relationship of stress to strain, whereby stress is equal to modulus times strain or

$$\sigma = E\varepsilon \tag{3}$$

There is a limit to the load-carrying capacity of any structure. The capacity depends on the material, physical dimensions, and the manner in which the load is applied. The load limit, measured in pounds per square inch, is much less if the load is cyclic in nature rather than a steady load, since the cyclic loading induces metal fatigue and subsequent failure of the structure. However, there is a minimum value (in terms of stress) called the "endurance limit" at which cyclic loading may be imposed for an indefinite time without subsequent failure.

A plot of the number of cycles required to fracture like specimens of a given metal against the various levels of strain each specimen is subjected to will produce a "stress--number of cycles (S-N) curve" (figure 2). From this plot, the endurance limit can be found.

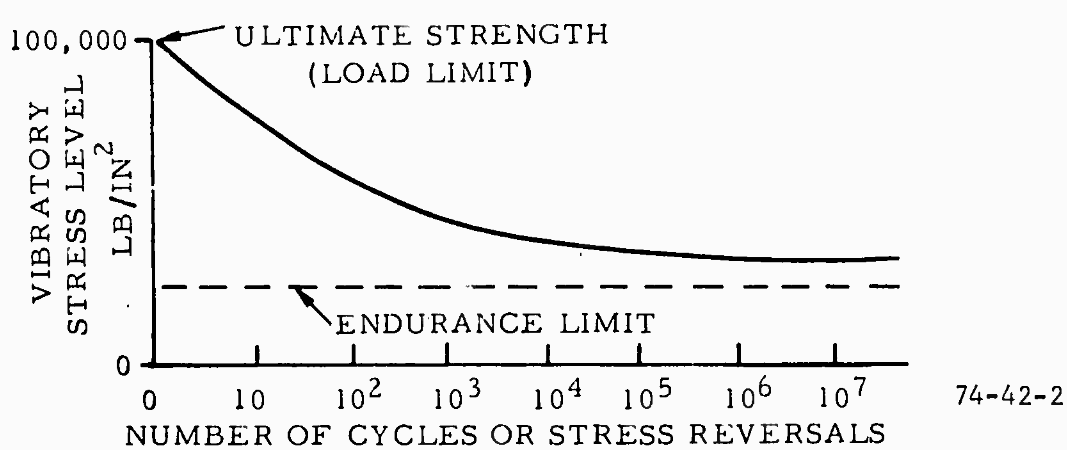

FIGURE 2. STRESS VS. NUMBER OF CYCLES (S-N) CURVE PLOT

A strain gage (figure 3) is used to procure accurate information about the magnitude, distribution, and direction of strain in a loaded structural body.

Because of the great number of gages available, one should be aware of the gage design characteristics in order to secure the most dependable and useful information.

The extreme environmental conditions encountered in a propeller stress survey demand attention to the smallest detail. Consideration must be given to the type of material under test. Operating temperature of the specimen as well as the gage excitation voltage, which will be largely dissipated as heat to the substratum, must be considered.

The strain range, grid length, size and configuration, and lead attachment as well as gage location are critical. Adhesive types, application methods and techniques are an art in themselves which are discussed later in the text.

TRANSMISSION OF STRAIN INFORMATION FROM PROPELLER TO RECORDING SYSTEM.

Early testing methods used a slipring and brush assembly such as shown in figure 4. Excitation power for the strain gages is carried via the electrical harness from the brush holder assembly connected to the brush and through the slipring assembly's polished contact surface. The back of the contact surface is connected to several terminal studs on the forward side of the slipring. These studs serve as a convenient mount to place balancing resistors as well as the attaching point for the electrical harness connecting the strain gages to the slipring assembly.

Years of development efforts resulted in improved slipring assemblies as shown in figures 5 and 6.

A variation of the aforementioned type of slipring is called the "pineapple." Pineapples are shaft-type slipring assemblies. The shaft carrying the slip-rings mounts on the axis of rotation and rotates with the test propeller. The stator rides on the shaft bearings and carries the brushes. Because of the requirement for stator restraint forward of the propeller, pineapples are seldom used on aircraft in flight. However, figure 7 does show a pineapple installation on a pusher-prop-type aircraft prepared for flight.

Although these systems represent vast improvement with respect to data transmission from the propeller to the recording instrumentation, there was room for further improvement.

This was manifested in the development of the FAA/Hamilton Standard Division (HSD), United Aircraft Corporation (UAC), system which eliminated the use of sliprings.

This is accomplished by an air-dielectric rotating capacitor, in which one plate rotates with the propeller while the other remains stationary, fixed to the engine (figure 8).

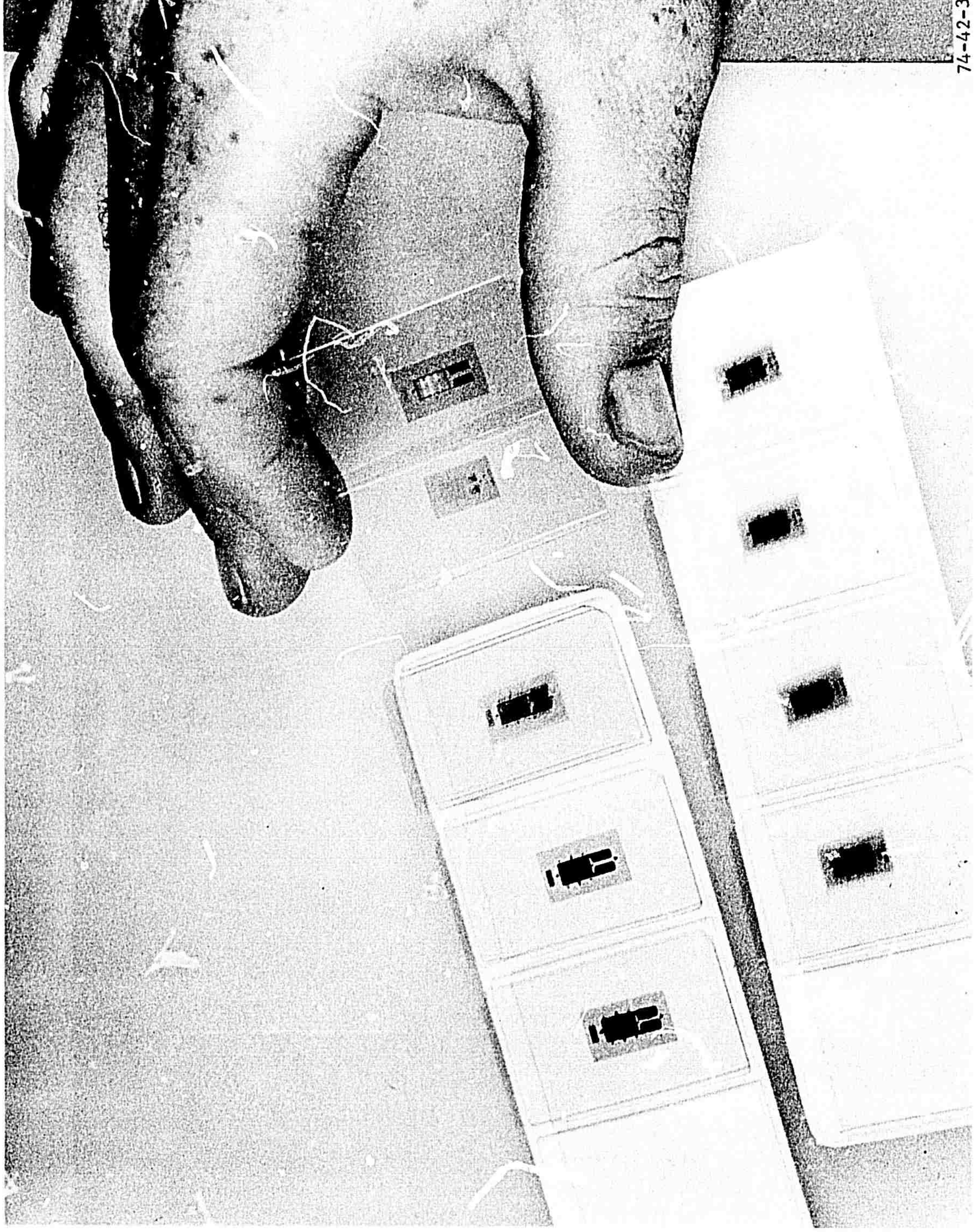

FIGURE 3. STRAIN GAGES

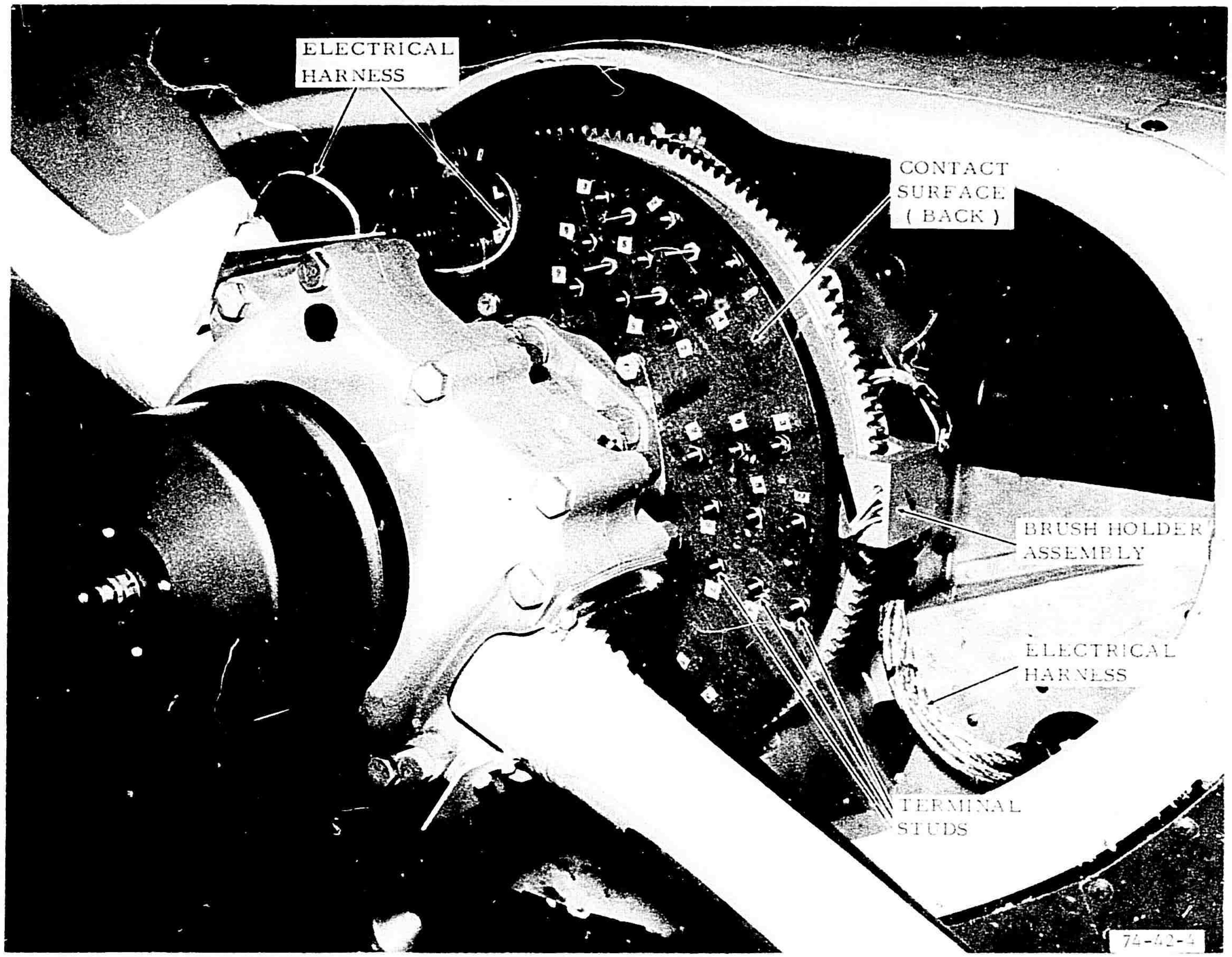

FIGURE 4. SLIPRING AND BRUSH ASSEMBLY

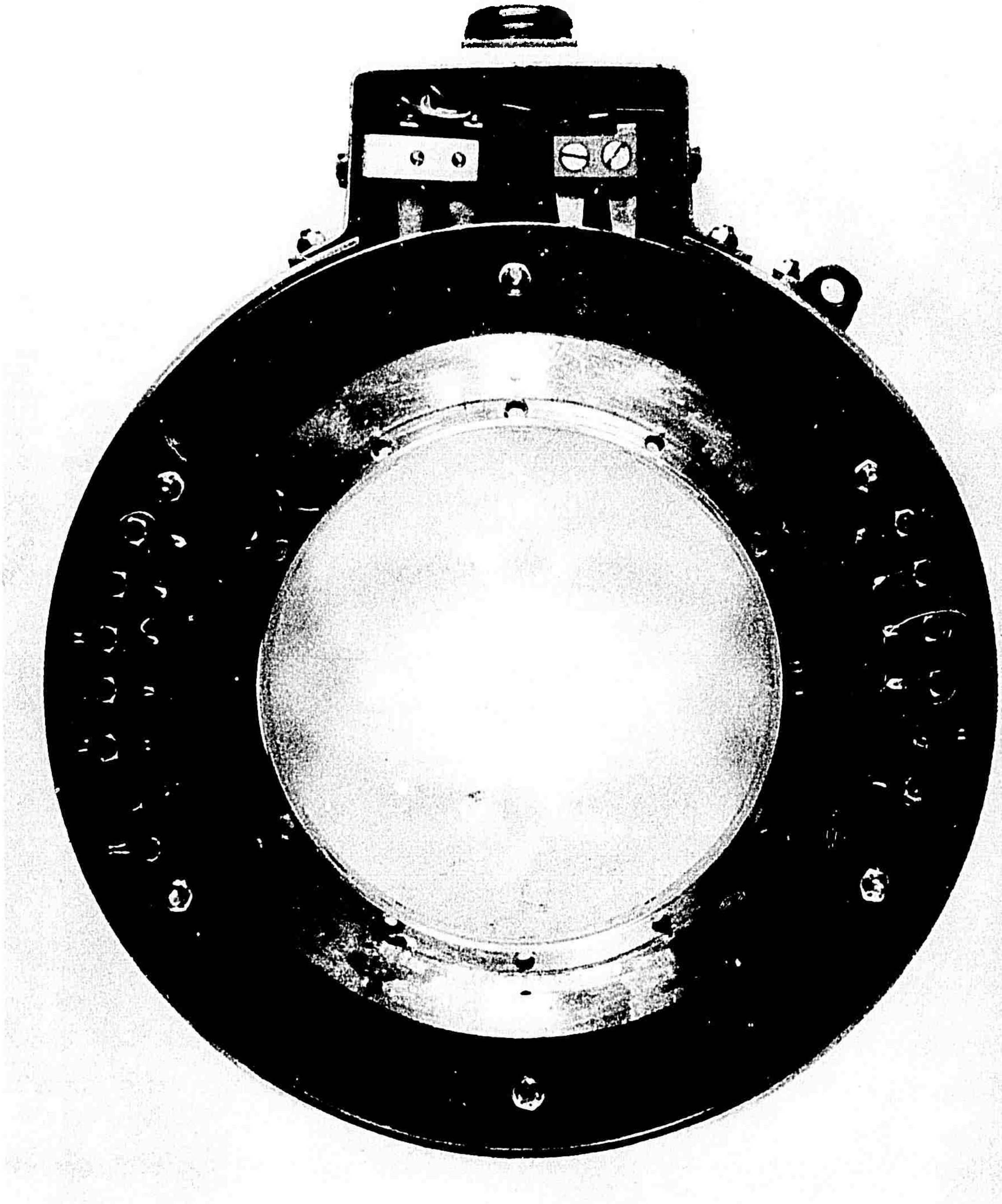

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FIGURE 5. IMPROVED SLIPRING ASSEMBLY

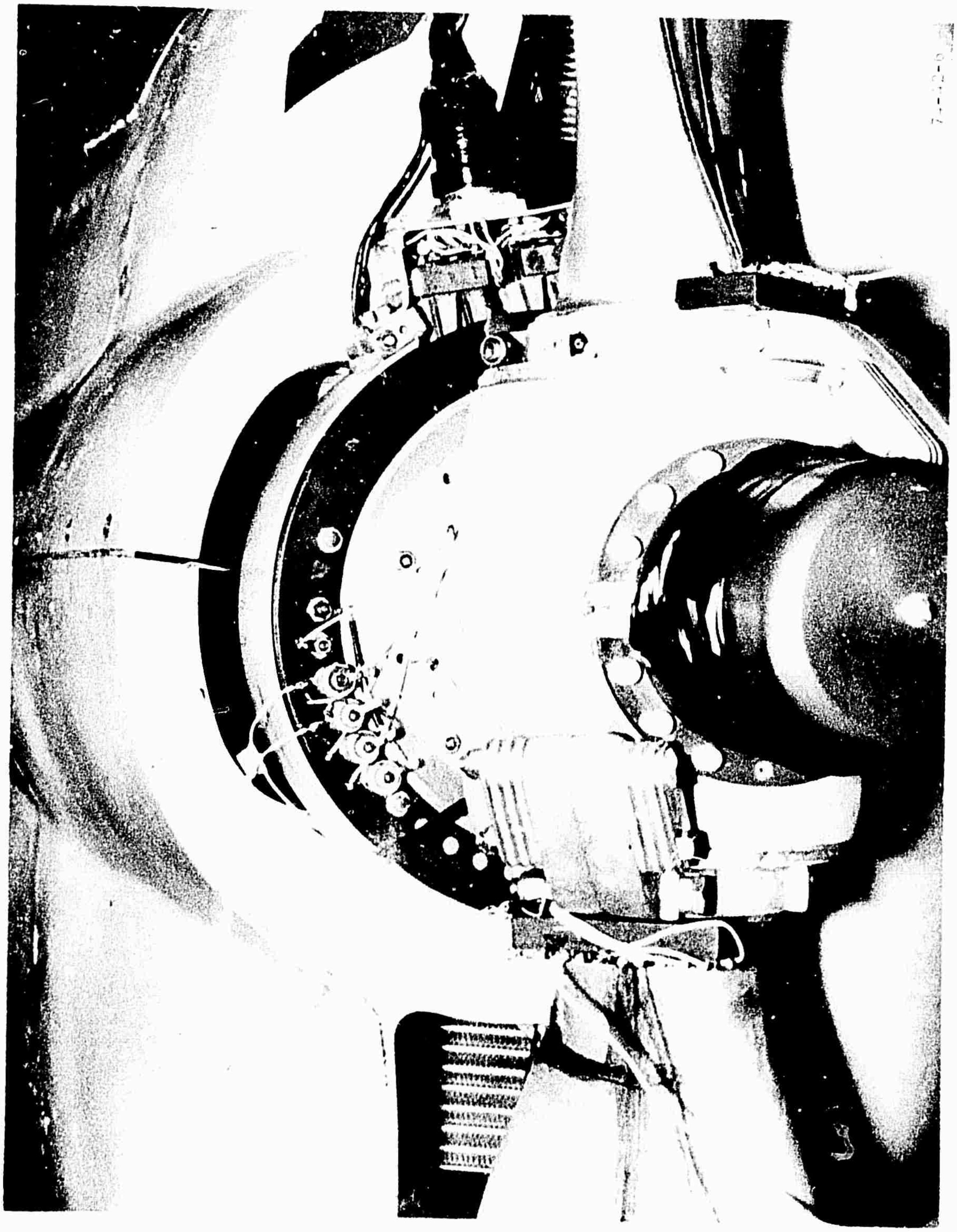


FIGURE 6. IMPROVED SLIPRING ASSEMBLY INSTALLED

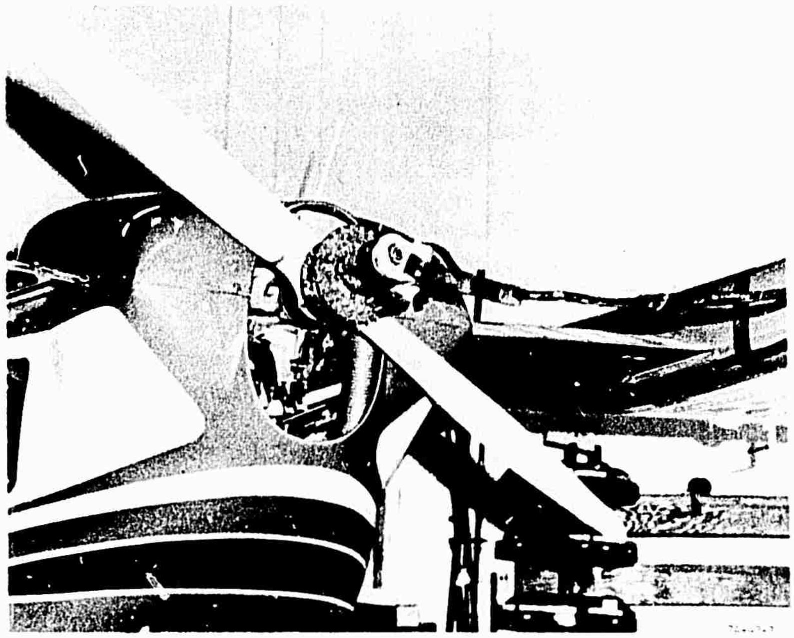


FIGURE 7. INSTALLED PINEAPPLE ASSEMBLY

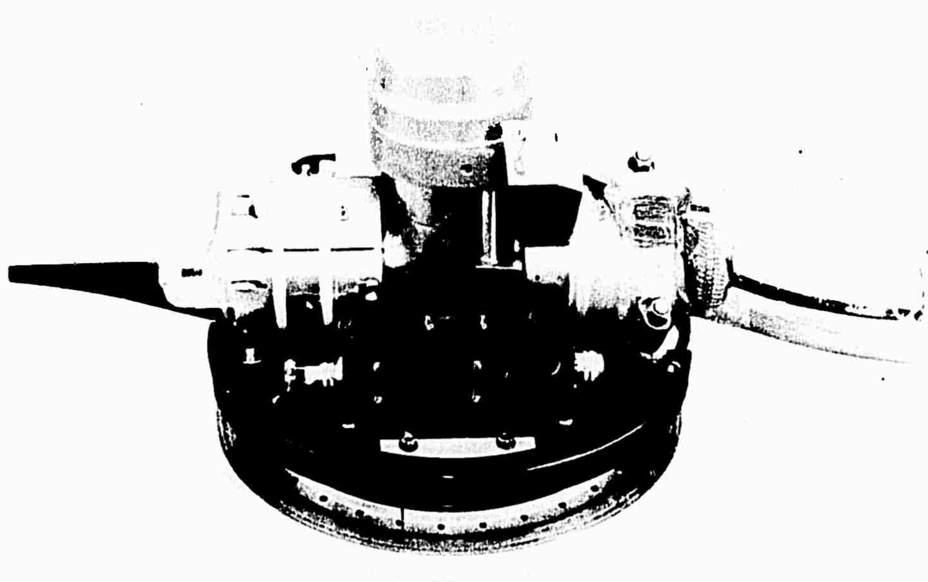


FIGURE 8. ROTOR ASSEMBLY--FAA/HSD SYSTEM

While this system was undergoing flight testing at the National Aviation Facilities Experimental Center (NAFEC), still another system evolved. This system uses miniature FM telemetry devices (figure 9).

In this system, a transmitter and battery power supply for each strain gage is mounted on the propeller close to the hub and the output signal is picked up by an antenna mounted nearby on the engine cowling.

In both the capacitive device and the FM telemetry device, the signal is passed from the propeller to the airframe without any mechanical connection. A representative block diagram is shown in figure 10 for all systems.

DATA RECORDING AND ANALYSIS

WAVE SHAPES AND OSCILLOGRAPHIC RECORDING.

A propeller making one complete revolution in one second is said to have a frequency of one revolution per second. A cycle is a period of time at the end of which a certain happening will reoccur. Therefore, if a propeller blade bends first in one direction, and then the other, the complete motion is called a "cycle." The number of bending cycles in a unit of time is the frequency. One unit of the process is a cycle, and the number of cycles in a unit of time, the frequency.

If a propeller were rotating 1,000 revolutions in a minute, and simultaneously bending back and forth twice each revolution, the bending frequency would be

$$1{,}000 \ \frac{\text{revolutions}}{\text{minute}} \times \frac{2 \text{ bending cycles}}{\text{revolutions}} = 2{,}000 \ \begin{array}{c}\text{bending cycles}\\ \text{per minute}\end{array}$$

or 33.3 cycles per second.

Strain gage data can be recorded in a number of ways, one of which is through the use of an oscillograph. In an oscillograph, the strain gage electrical signal is converted into equivalent light signals and recorded on moving light-sensitive rolls of paper.

This is accomplished by connecting the strain gage signal to a galvanometer. The galvanometer, being extremely sensitive to changing electrical energy passing through it, causes a small mirror fixed to it to move in response to variations in the input signal to the galvanometer.

A fixed-light source directs its light rays onto the mirror, which, as it moves, reflects these rays to a focusing lens and then to the moving photosensitive paper for recording.

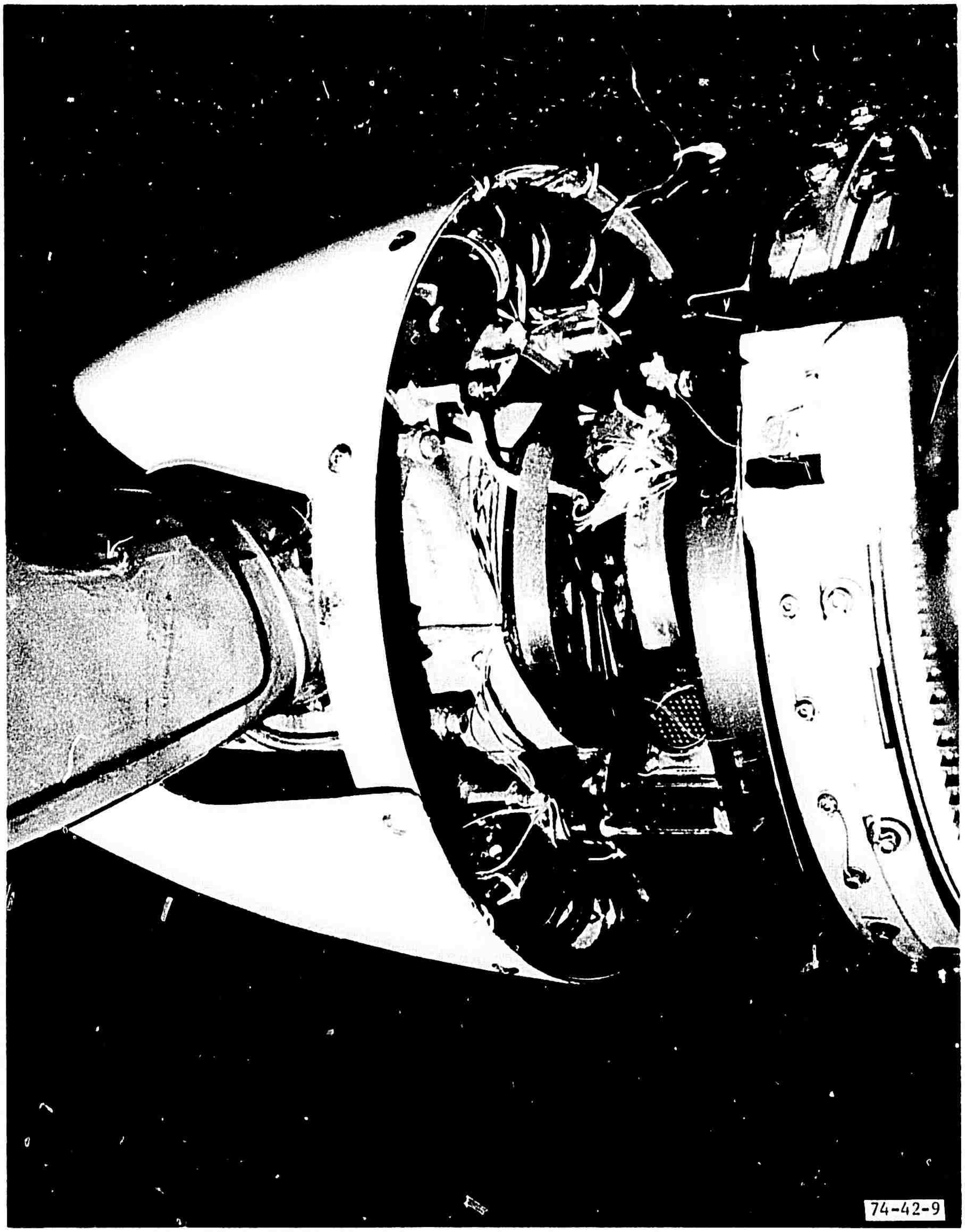


FIGURE 9. ¹'M TELEMETRY TRANSMITTERS

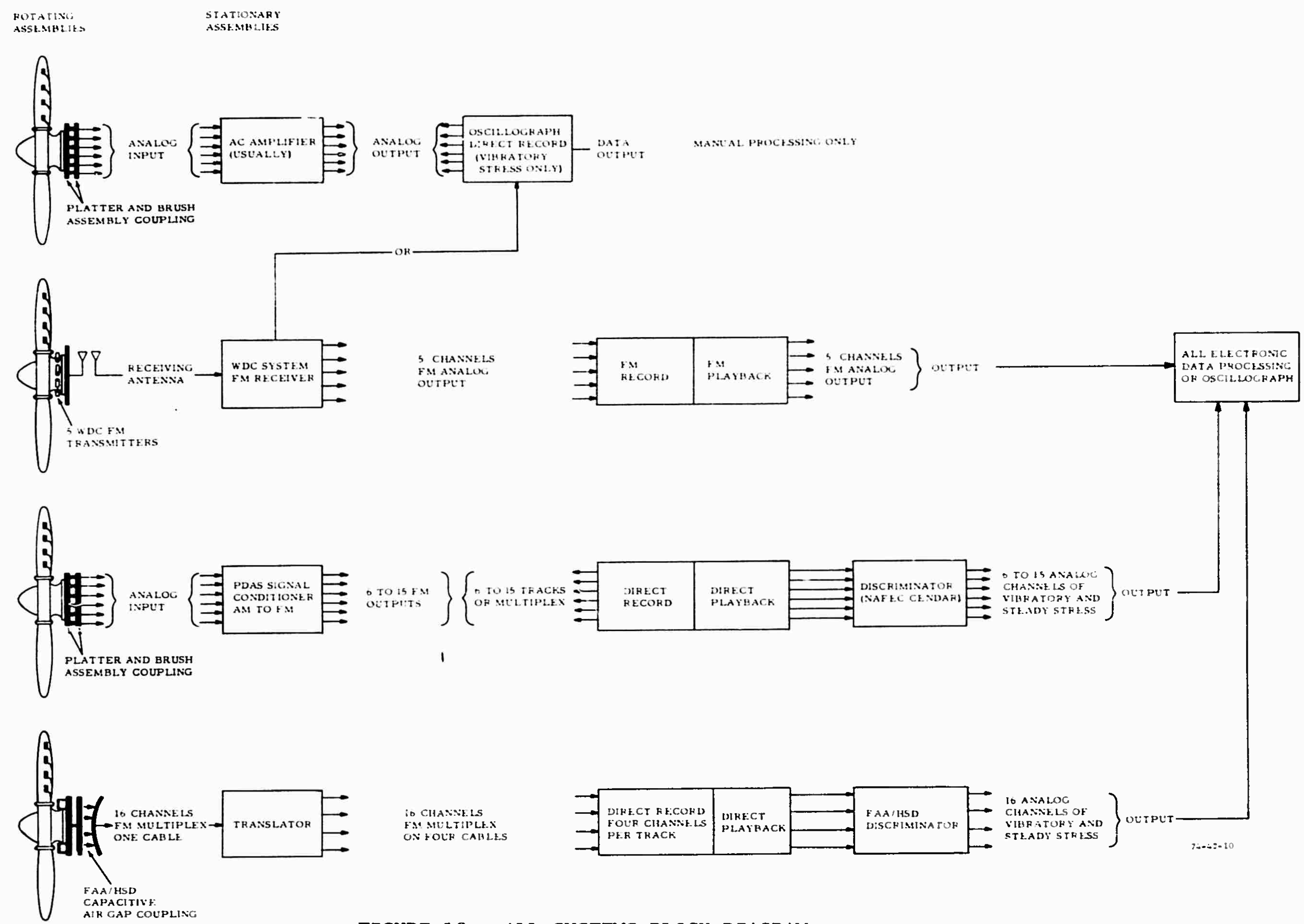


FIGURE 10. ALL SYSTEMS BLOCK DIAGRAM

Galvanometers are manufactured in a number of types differing in frequency response and sensitivity. The former refers to the rapidity with which the galvanometer will respond to changing input signal, while the latter refers to the amplitude of the reflected light beam per unit value of input signal.

A galvanometer with a flat frequency response of zero to 1,920 hertz (Hz) and a sensitivity of 1.7 inches per volt means that when a 1-volt input signal having a frequency of 1,920 Hz or below is applied to the galvanometer terminals, the recorded light beam will deflect an amplitude of 1.7 inches 1,920 times between the 1-second timing marks.

Thus, timing lines placed on the paper can be used to determine the frequency of the input signal.

In the simplified oscillogram illustrated in figure 11, an inspection will reveal the stress frequency in terms of propeller speed and hertz (cycles per second).

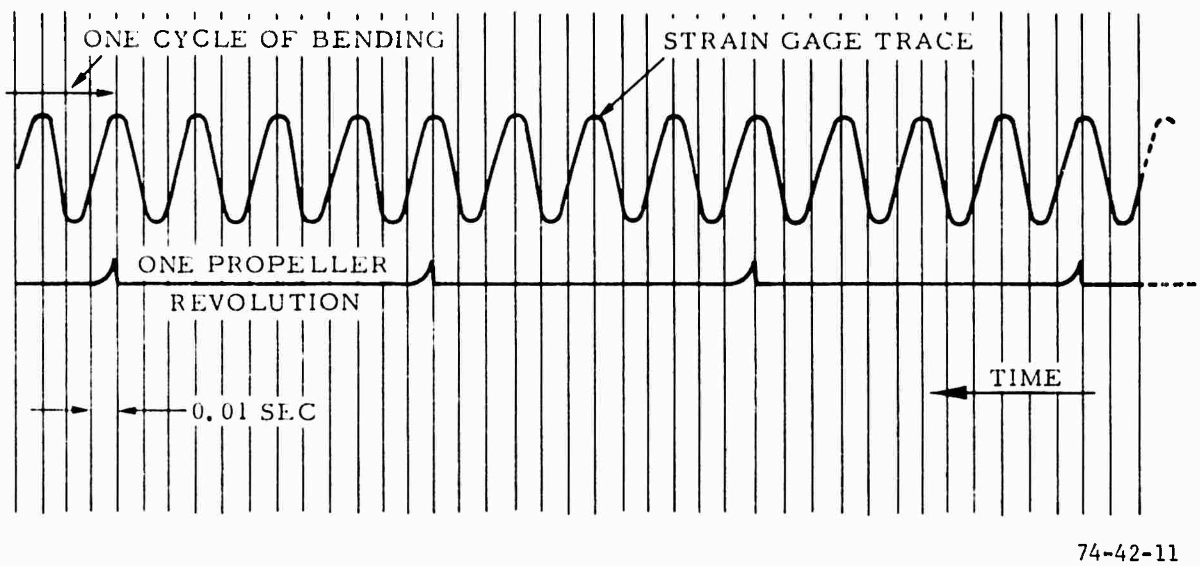


FIGURE 11. SIMPLIFIED OSCILLOGRAPH OUTPUT SAMPLE

The stress frequency is obtained by counting the number of bending cycles which occur during one revolution of the propeller or during an interval of time, usually 1 second.

It should be noted that the same geometrical relationship should exist between the timing lines and the stress trace at the end of the count as at the beginning.

The waveforms normally encountered in propellers, unfortunately, are more complex. A complex waveform will result whenever two or more simple waves are combined.

The following plot (figure 12) illustrates the manner in which these simple waves combine to form the complex wave. Note that if the illustration were continued, the pattern would repeat itself.

The numerical value of the sine components, which combine to form the given pattern, indicate the source or cause of the bending. It is on the basis of this information that corrective action can be taken to reduce or eliminate an undesirable stress condition.

The task of analyzing vibratory propeller stress data involves the measurement of the trace amplitude and wave spacing, calculation of the stresses and frequencies, and then the plotting of the results.

The calculation and plotting of amplitudes might be called the quantitative aspect ("how much") and the determination of stress frequencies as the qualitative ("what kind").

The process of deriving this information is laborious and often subjective. In addition, to obtain any kind of higher frequency response over a 30- to 40-second operational setting, the oscillograph paper speed results in a great volume of recording paper in the aircraft. If data recording is limited to short bursts, on the other hand, critical transients may be overlooked.

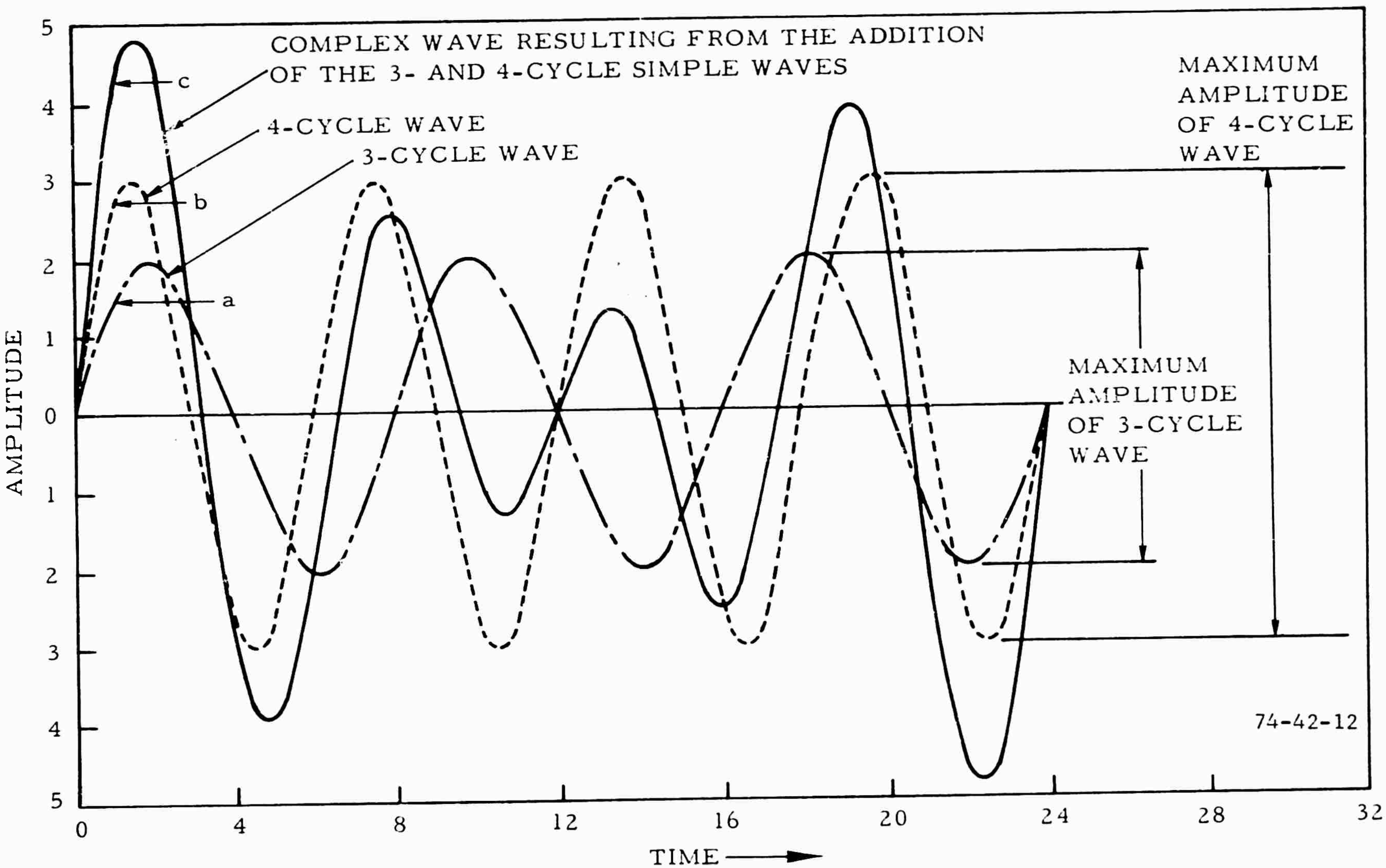
Oscillographic recording normally is concerned with only the vibratory component of the total stress, the steady component being assumed sufficiently accurate when calculated from the centrifugal and thrust forces on the propeller, which combine to produce the steady stress at a given flight operating condition. Figure 13 defines steady, vibratory and total stresses.

When obtainable, the quantities usually considered in propeller dynamic stress analysis are the peak stresses ($\pm$) and the mean or steady stresses.

MAGNETIC RECORDING.

Modern magnetic tape recording equipment offers numerous advantages in acquisition and reduction of vibration data; a much greater capacity, higher frequency response, the ability to "refly" test flights, data processing in more than one manner and in "real time," and capability of processing data more than one time.

The fundamental process of recording data directly on the tape, known as direct recording, is the basis of all magnetic tape recording systems. All other methods of impressing data are to be considered as variations of the direct method. Direct recording, however, is the optimum process for all application requirements for a reasonably linear transfer characteristic combined with maximum high frequency limit for any given tape speed.



THE RESULTANT COMPLEX WAVE IS ARRIVED AT BY ADDING THE AMPLITUDE OF THE 4-CYCLE WAVE TO THE AMPLITUDE OF THE 3-CYCLE WAVE AT EVERY INSTANT OF TIME.

FIGURE 12. COMPLEX WAVEFORM

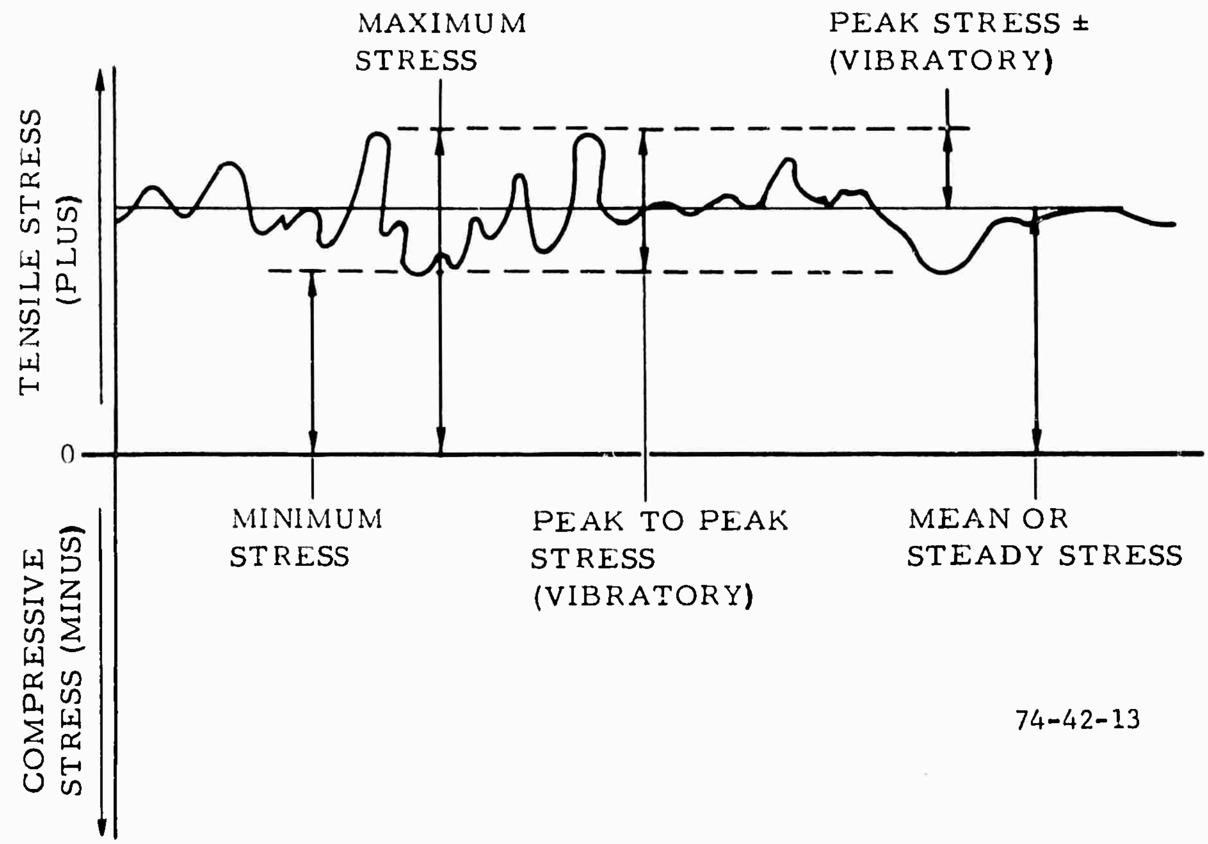


FIGURE 13. OSCILLOGRAPHIC RECORDING OF STRESS VARIATION

Major limitations of the direct recording process are caused mainly by a weakness in mechanical systems used to transport the tape across the record/ reproduce heads and by the tape itself, rather than by the electronic system or transducers.

A carrier frequency of constant amplitude and frequency contains no intelligible information. In order to make use of it, the carrier wave must be changed or modulated.

Modulation can be a variation of the amplitude or the frequency of the carrier wave.

In amplitude modulation (AM) figure 14, the amplitude of the carrier frequency varies in accordance with the modulating signal.

In frequency modulation (FM) figure 15, the carrier frequency is affected and not the amplitude.

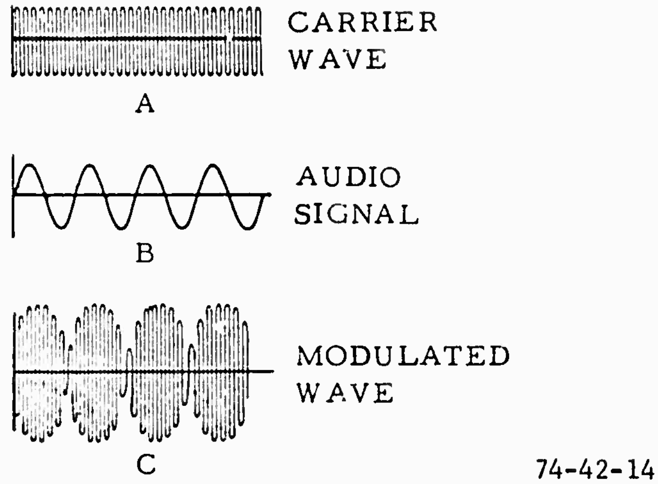


FIGURE 14. AMPLITUDE MODULATION (AM) WAVEFORM SAMPLES

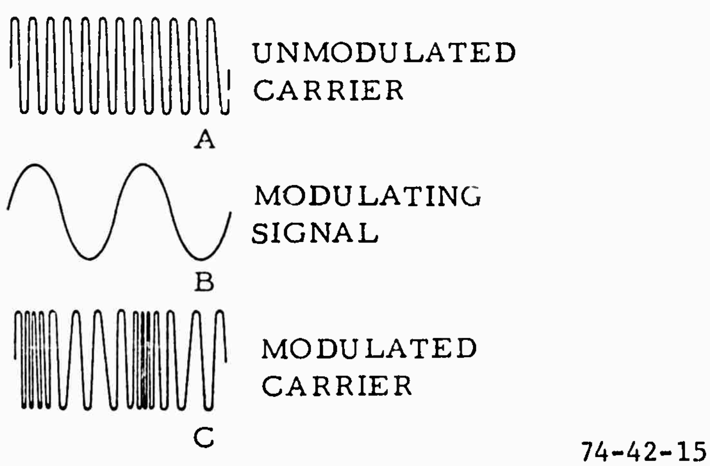


FIGURE 15. FREQUENCY MODULATION (FM) WAVEFORM SAMPLES

In propeller vibration work, direct recording has the same limitations as audio frequency sound recording; namely, a loss or absence of response at the low frequency end from about 40 down to zero Hz direct current (d.c.). Since this range often encompasses the first and second order components of the vibration (vibration frequency divided by engine speed), as well as the d.c. or steady stress component, it is of major interest in the analysis. For this reason, the strain gage signal output voltage is used to modulate an FM carrier of much higher frequency which can be recorded directly on magnetic tape without loss of response. In order to restore the strain gage signal to its original form, it is then necessary to demodulate (or discriminate, detranslate) the FM data. Another advantage of FM is that carrier frequencies can be selected which are far enough apart when modulated so as not to interfere with each other, thus permitting several signals to be recorded on one magnetic tape track or "multiplexed."

ELECTRONIC DATA PROCESSING.

Once the data are recorded on tape and can be played back, they are amenable to electronic rather than manual processing. Some commercially available, special-purpose instruments designed for such use are as follows:

1. The spectrum analyzer, which scans the incoming data and produces a signal which is a function of the frequency spectrum of the data (frequency components making up the complex wave) (figure 16a and b).

2. The amplitude probability analyzer, which produces a signal which is a function of the distribution of data amplitudes encountered during any given period. This information can be used to derive peak and steady-stress amplitudes (figure 16c).

3. The cumulative amplitude distribution analyzer, which presents much the same information as the amplitude probability analyzer, but in a different form. This analyzer indicates the distribution of amplitudes between zero and maximum values (figure 16d).

4. Correlators, which can indicate the degree of autocorrelation of a signal in any given function time or degree of cross-correlation between two different functions as they are displayed in time (Γ) with respect to each other (figure 16e).

5. The time of event indicator, which can be used to detect the occurrence of a transient whose amplitude is above a preset value and which notes precisely when it occurred.

6. Comb filters, which can be used to give a quick-look indication of any significant peak which might occur in the data and which can then be studied in more detail with some of the previously mentioned equipment.

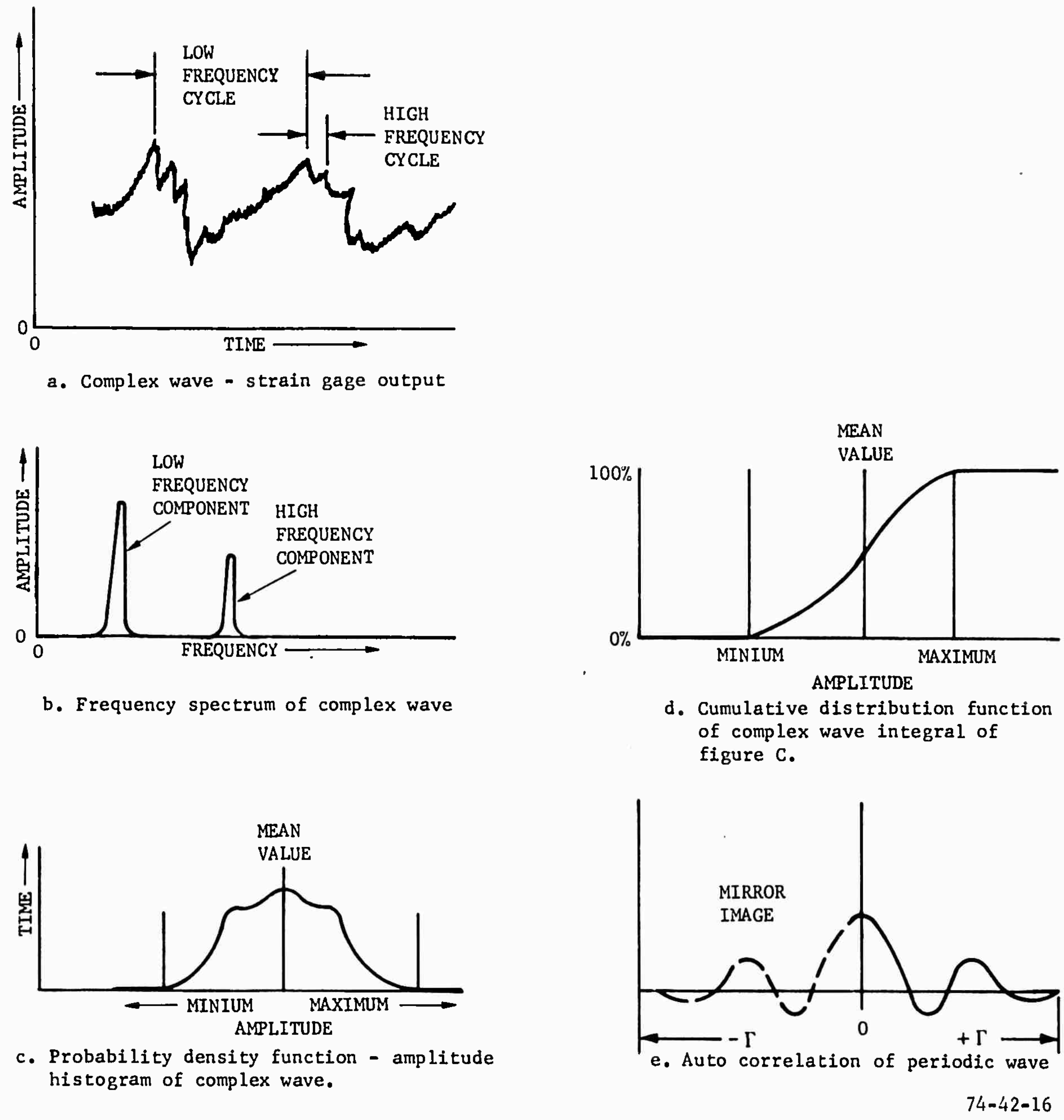


FIGURE 16. SAMPLES OF ELECTRONICALLY PROCESSED DATA

With such electronic equipment, many hours of magnetic tape can be reduced and analyzed in many forms in a relatively short time, especially if a programmable calculator or minicomputer and automatic plotting equipment is available. This is opposed to oscillographic recording which would make even attempting to obtain many hours of continuous stress data impractical.

On many aircraft, such equipment carried onboard for the flight testing program permits selective testing with resultant savings in time and expense. The outputs of this equipment can be observed in real time on an oscilloscope and/or a peak-reading device in flight.

If special-purpose equipment is not available, however, the data, after discrimination (conversion from FM to analog form), can be re-recorded on oscillograph paper. By measurement of the recorded waveforms, values of peak stress and the predominant frequency components can be taken as previously outlined.

DESCRIPTION OF VARIOUS PROPELLER DATA SYSTEMS

SLIPRING AND BRUSH WITH OSCILLOGRAPH RECORDING.

The slipring and brush assembly, in its various forms (as previously described), is the oldest data transmission device still in use (figure 17). Used with a basic audio frequency amplifier for each channel, each strain gage output eventually drives a light beam galvanometer in the oscillograph, creating multiple traces on moving light-sensitive paper. Since the amplifiers respond only to alternating inputs and the strain gage bridges used with the common excitation of most slipring assemblies are subject to drift, this system is not normally capable of acquiring and transmitting the steady or nonvibratory components of the propeller stress.

SLIPRING AND BRUSH WITH FM RECORDING.

The portable data acquisition system was a small, lightweight analog magnetic tape data system developed at NAFEC, and intended for use in small general-aviation aircraft (figure 17).

Signals originating at the propeller-mounted strain gages are routed to the input side of the signal conditioner which is adjusted to output a voltage level of zero to plus 5 volts or 2.5 volts above or below zero.

An additional function of the signal conditioner is to substitute a reference voltage in place of the incoming signals. The substitution voltage is utilized to calibrate at two levels, usually zero volt and either 2.5 or 5 volts.

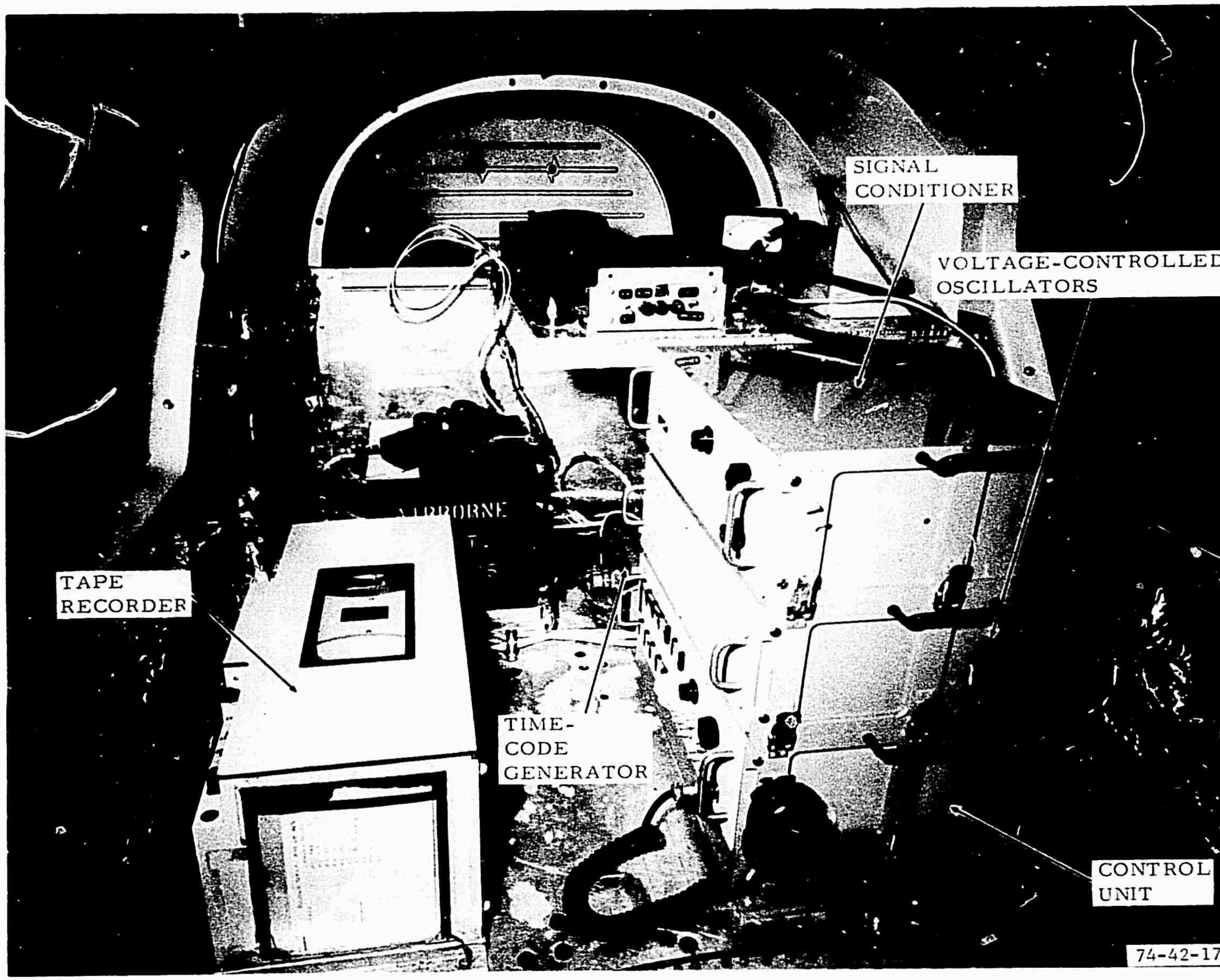


FIGURE 17. PORTABLE DATA ACQUISITION SYSTEM

The electrical signal is routed to voltage-controlled oscillators (VCO's) where the voltage is changed to a specific frequency range. The portable data acquisition system contains 30 VCO's with center frequencies ranging from 400 to 30,000 Hz. The output of as many as 15 of these VCO's may be totaled with a reference oscillator and recorded on one track of a magnetic tape recorder. The frequency response of a VCO varies with its center frequency and includes the range of 6 to 450 Hz.

The tape recorder is a seven-track analog magnetic tape recorder. One track is assigned to voice, one track to time, and the remaining five tracks are available for data.

A control unit serves to start and stop the recorder, as well as control the calibration. The control unit also allows monitoring of input signals as well as output of the reproducing amplifiers on the recorder.

A time-code generator, built into the portable data acquisition system, is used to record coded time on the magnetic tape. This time is subsequently used to seek out specific data for processing.

At NAFEC, the recorded information was discriminated and processed using a variety of means. Peak vibration and mean stress at each flight operating condition were taken from peak stress amplitude histograms and plotted against the variable parameter. Power spectra were then taken and automatically plotted for the data points of unusually high or unexpected stress levels. This process involved a real time spectrum analyzer, correlator, and a programmable calculator and plotter.

FAA/HSD SLIPRINGLESS SYSTEM.

This 16-channel data system represented by block diagram (figure 18) provides for the modulation of constant bandwidth VCO's by low-level strain gage signals. Each VCO operates about a specific center frequency and the resultant FM outputs are linearly combined in a mixer amplifier. The mixer output, consisting of 16 FM carriers from 16 to 136 kilohertz (kHz), is then connected to one side of the capacitor coupling, composed of an engine-mounted stator and a propeller-mounted rotor. The electrical power for the propeller-mounted rotor and for the propeller-mounted system is generated by the rotary motion of the propeller in conjunction with a stationary magnet assembly and a rotating winding. The alternating current (a.c.) output of the alternator is rectified, filtered, and regulated in the power supply (figure 19) to provide both the 12.8 volts, direct current (Vd.c.) strain excitation and the 28 Vd.c. for the electronic equipment. In addition, a signal with a frequency proportional to propeller speed is obtained from the power supply and included at the mixer. The input to the engine-mounted line driver is obtained from the capacitor stator. The stationary (onboard) equipment prepares the FM data for recording on an airborne tape recorder. The amplified line driver output then drives a group of five filters. The 2 kHz low pass removes the r/min signal from the spectrum and the four bandpass filters divide the 16 VCO bands into four groups of four carriers. The bandpass

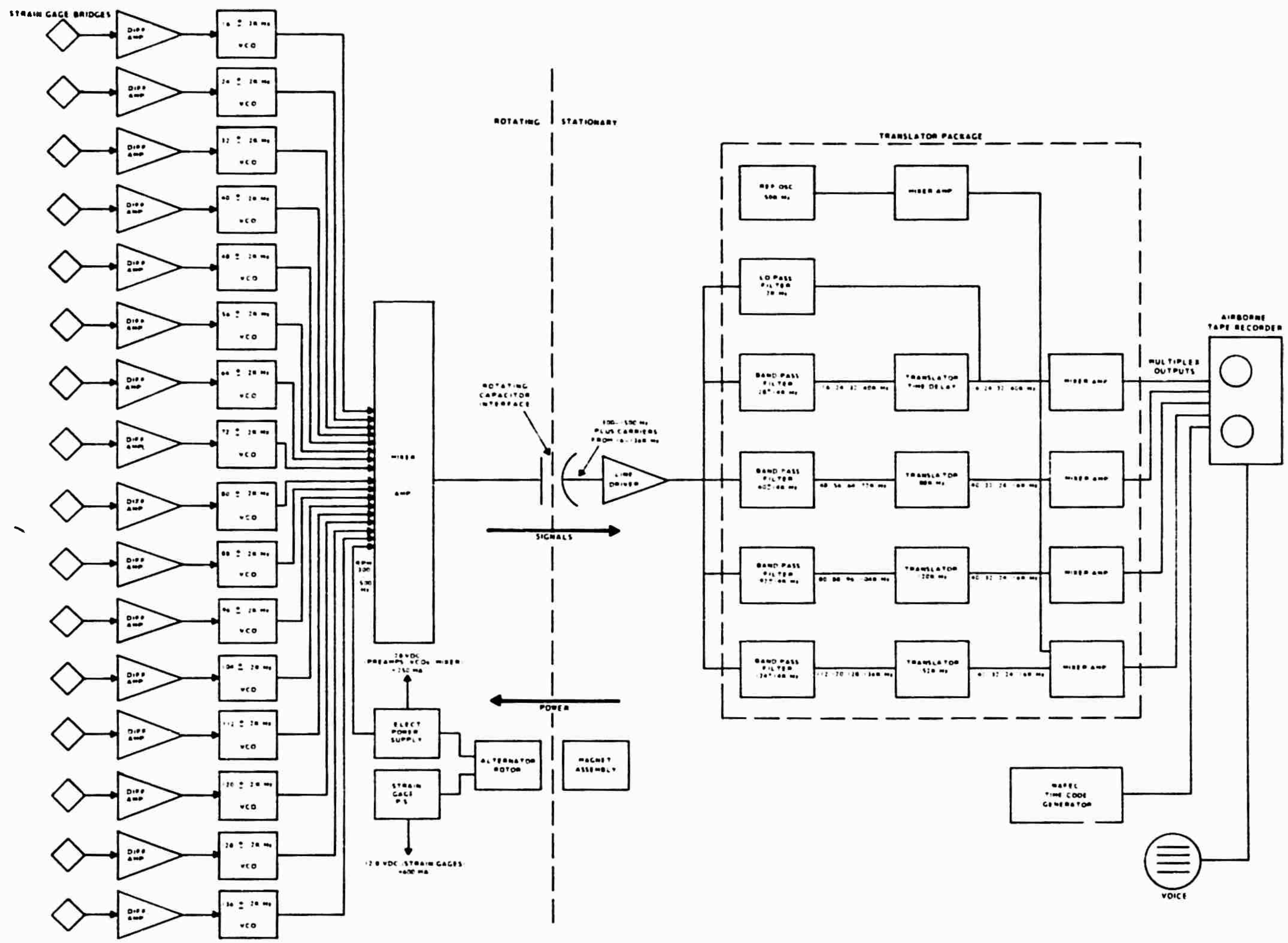


FIGURE 18. PROPELLER MEASUREMENT SYSTEM (BLOCK DIAGRAM)

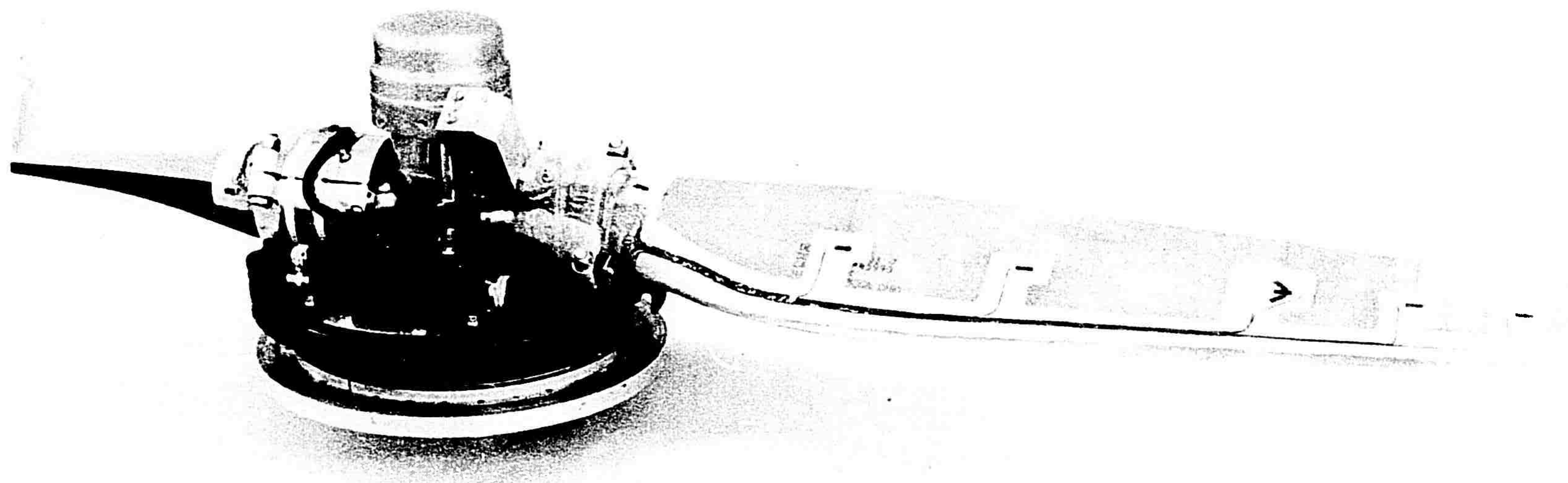


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FIGURE 19. CAPACITOR ROTOR

filter outputs are heterodyned in the translators to produce four groups of carriers from 16 to 40 kHz. The output from a 50 kHz reference oscillator is then combined with each group of carriers and then recorded with a 50 kHz bandwidth tape recorder.

The blade locations selected for strain measurement were chosen to cover the normal flatwise, edgewise, and torsional modes of propeller vibration deemed to be of prime concern. The selected locations also served to define the steady strain distribution on the blade.

The signal-conditioning equipment in this data system provides several functions: strain gage bridge completion, a method to electrically balance the completed strain gage installation, low-level differential input with high common-mode rejection, and conversion of the strain gage bridge outputs to narrow-band frequency modulated subcarriers.

The electrical connections to the signal-conditioning package are arranged so that a three-wire lead system must be used with the strain gages, that is, three separate wires are run to each propeller-mounted strain gage. Two of the three wires are used to provide the strain gage excitation current and the third wire provides the signal input to the VCO preamplifier. This technique is used to provide temperature compensation of the lead wires.

Electrical balance is provided by the plug-in, repairable module illustrated in figure 20. The module plugs into the signal-conditioning package and uses miniature metal film resistors to shunt the appropriate bridge arm. The resistors are potted in Sylgard 184, which can be cut away to change the resistance value in a future installation.

Before the proper values of shunt resistance can be incorporated in the balance modules, an assessment must be made of the approximate maximum values of steady and vibratory strain to be encountered in each data channel. Then a zero (no strain) level is selected to allow the data channel to remain within its designated bandwidth when the maximum strain levels are realized. For example, estimated maximum strain levels for the propeller instrumented in the test program are as shown in table 1.

TABLE 1. PROPELLER STRAIN LEVELS

Blade Station	Steady State Stress (Tension) (lb/in^2)	Vibratory Stress ($\pm lb/in^2$)
Shank Leading Edge	8,000	3,500
Shank 90° from Leading Edge	8,000	3,500
35 Percent Radius	10,000	3,000
50 Percent Radius	10,000	3,000
70 Percent Radius	8,000	5,000
80 Percent Radius	6,000	5,000
88 Percent Radius	3,000	5,000
70 Percent Radius (Shear)	1,000	1,000

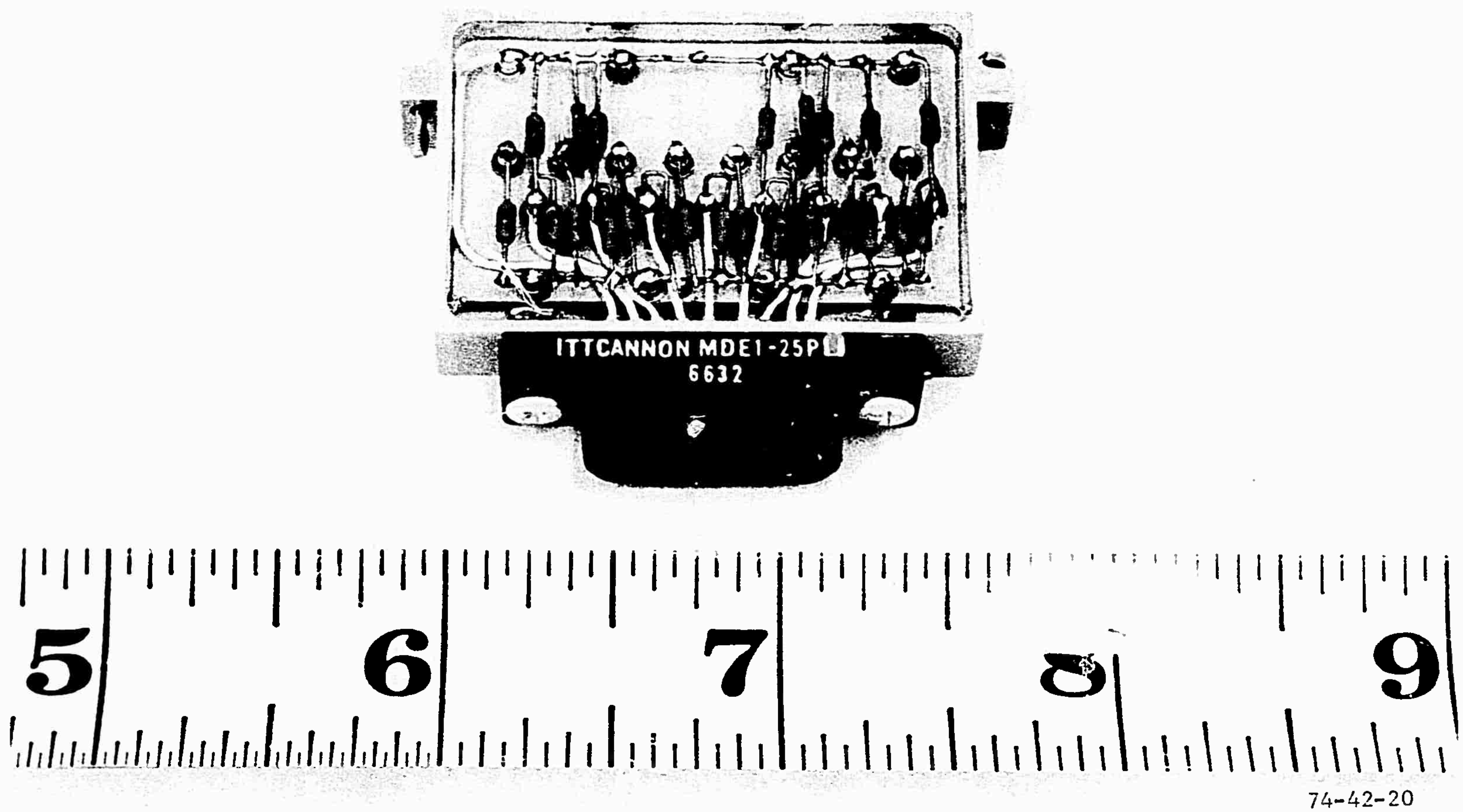


FIGURE 20. STRAIN GAGE BRIDGE BALANCING MODULE

The equivalent full scale of the bending data channels can be calculated with the equation:

$$\frac{e_o}{E_{exc}} = \frac{SG_f}{4E} \tag{4}$$

where: e_o = Strain gage bridge output volts

E_{exc} = Strain gage bridge excitation volts = 12.8

G_f = Gage factor

S = Stress, pounds per square inch (lb/in^2)

E = Young's modulus for propeller material

In order to provide a zero strain point, which will not allow the total strain excursion to exceed full scale or negative vibratory peaks to be less than zero input (for channels where peak vibratory signal exceeds the level of the steady component), each data channel was placed between 10 and 30 percent of full scale.

The actual balancing is accomplished with the final strain-gaged propeller connected to the data system. Power is applied to the system with the calibration setup used for checkout of the system. The frequency of each VCO is measured with a counter and appropriate shunt resistors are included in the balance module.

Since the output from the strain gages is a low-level signal (millivolts), voltage gain is required to raise the signal level to a value sufficient to drive the VCO's. The preamplifiers used in this data system are paired with the VCO's.

The common-mode rejection ratio of the preamplifier used in this data system is specified as a minimum of 80 decibels (dB) at direct current (d.c.). A further technique has been used on this data system to help eliminate the cross-talk effects of common-mode voltage. The power supply circuits are designed so that the strain gage bridge outputs are effectively held at the system common potential instead of one-half the bridge excitation voltage.

In the illustration (figure 21) of a typical strain-gage bridge circuit, for example, one-half of the excitation voltage appears at the preamplifier input as a common-mode signal; that is, both sides of the preamplifier input are above ground by one-half of the excitation voltage. Likewise, any noise power, which is coupled into the strain gage circuit through electromagnetic and electrostatic pickup, will also appear at both inputs as a common-mode voltage.

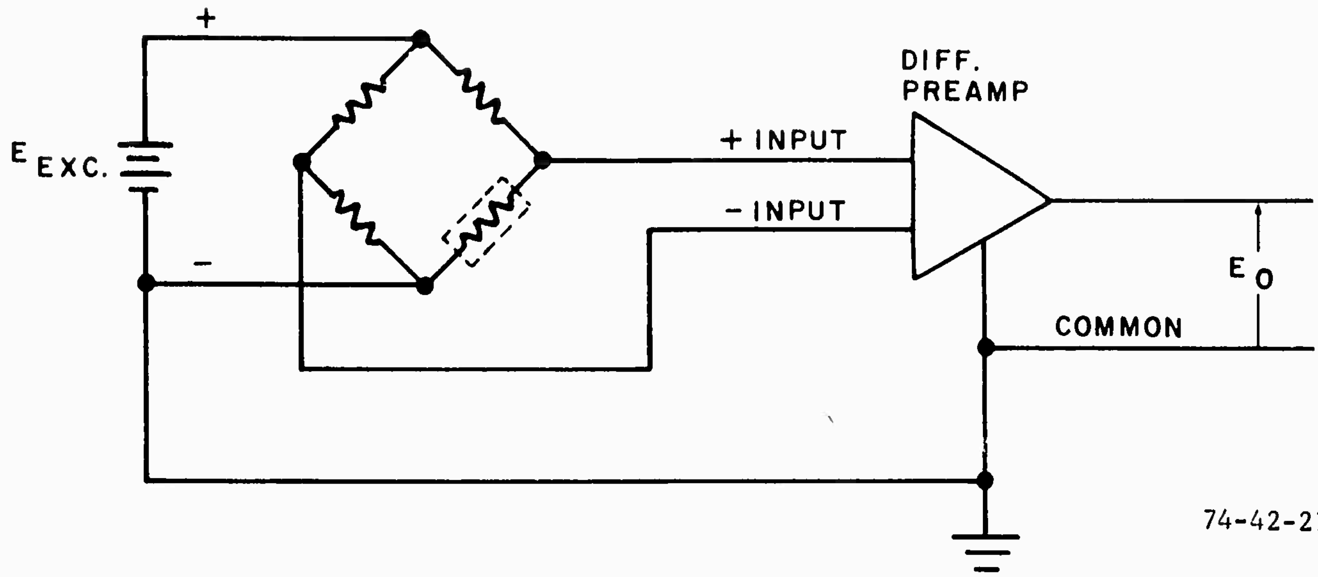


FIGURE 21. STRAIN GAGE BRIDGE COMMON MODE CIRCUIT

The function of the VCO is to convert the voltage output of the preamplifier, which represents strain to an FM subcarrier. This is accomplished by making the frequency deviation of the VCO output proportional to the input voltage; that is, the VCO operates at lower band edge (LBE) when the input is zero and the VCO is at the upper band edge (UBE) for a 5-volt input. For example, the 16 kHz (center frequency) VCO will operate at 14 kHz with zero input and 18 kHz for full-scale input. Then the total deviation for each channel is 4 kHz (±2 kHz of center frequency) and the available frequency response is from zero Hz to 1 kHz.

Coupling of the FM multiplex from the rotating propeller to the nonrotating line driver (block diagram, figure 18) is accomplished with a passive element. This element is an air-dielectric capacitor composed of a stator plate sandwiched by two rotor plates.

The output of the line driver amplifier contains the entire propeller measurement spectrum including the r/min signal and the 16 FM subcarriers. This complete signal could be recorded on a direct record tape track except for two important factors. First, the high frequency carriers employ small percentage deviations (±1.47 percent for the 136 kHz carrier), which would present a problem in obtaining an adequate signal-to-noise ratio when the tape-recorded data were demodulated during reproduction; that is, the tape record and playback machine's "wow" and flutter would require compensation beyond the ability of currently available discriminator equipment. Secondly, recording of a relatively high-frequency composite on one tape track would not utilize the tape in an efficient manner and, therefore, would significantly reduce the available recording time.

In order to avoid the signal-to-noise ratio problem due to flutter and to obtain the maximum practical recording time, frequency translation is used prior to tape recording to form four groups of carriers from 16 to 40 kHz.

Table 2 lists the data pertinent to the system VCO's.

TABLE 2. VCO INPUT FREQUENCY RESPONSE

Center Frequency (kHz)	LBE (kHz)	UBE (kHz)	Deviation from Center (Hertz)	Frequency (±) (Percent)
16	14	18	2000	12.50
24	22	26	2000	8.33
32	30	34	2000	6.25
40	38	42	2000	5.00
48	46	50	2000	4.17
56	54	58	2000	3.57
64	62	66	2000	3.13
72	70	74	2000	2.78
80	78	82	2000	2.50
88	86	90	2000	2.27
96	94	98	2000	2.08
104	102	106	2000	1.92
112	110	114	2000	1.79
120	118	122	2000	1.67
128	126	130	2000	1.56
136	134	138	2000	1.47

Note: LBE = Lower Band Edge, UBE = Upper Band Edge

The electrical power for the data system is provided by an alternator, which is a part of the propeller-mounted hardware. The alternator employs two rotating windings in conjunction with a stationary magnet assembly to generate the required electrical energy. A stator is split into two sections to facilitate assembly and removal without disassembly of the test propeller.

The four subcarrier groups, each containing carriers at 16, 24, 32, and 40 kHz, are combined with a 50 kHz reference oscillator, which can be used on data playback for tape speed compensation. The compensation available in the discriminators (used in the FAA data reduction facility) will be compatible with the frequency deviation appearing on the translated channels.

Channel Center Frequency	Percent Deviation (±)
16	12.50
24	8.33
32	6.25
40	5.00

The filtered r/min signal is also mixed with one of the subcarrier groups, occupying the spectrum from approximately 400 to 1500 Hz.

The system frequency translation equipment is housed together with the aircraft supporting parameter circuitry in a one-half airline transport rating (ATR) case as pictured in figure 22. The front panel includes the four multiplex output connectors for tape recording and the parallel monitor outputs which are used to observe the data on the monitor discriminators. Also available for observation at the front panel are the r/min and IP pulser

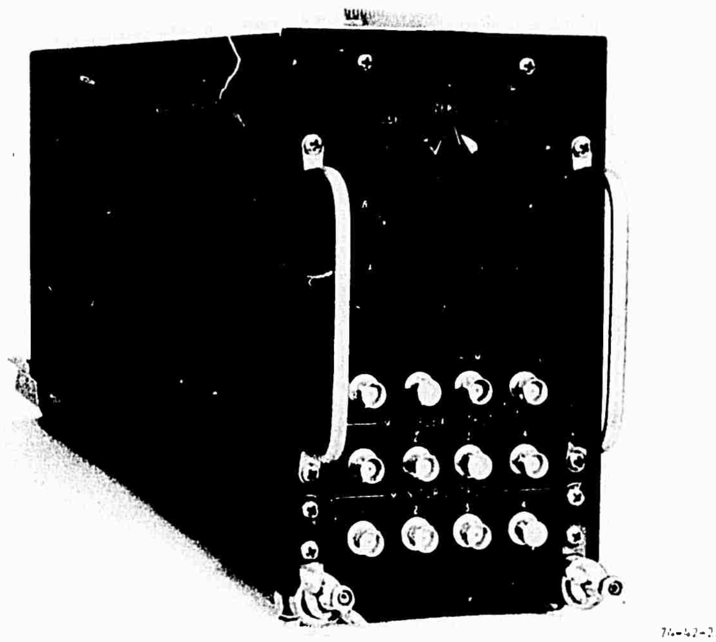


FIGURE 22. TRANSLATOR AND AIRCRAFT PARAMETER EQUIPMENT

Seven data channels are included in the translator package to provide for the measurement of several parameters, which are required to define the aircraft operating conditions. These data channels include transducers, calibration circuits, and VCO's for the recording of deck angle, manifold pressure, landing gear position, altitude, vertical acceleration, and airspeed. In addition, a channel is included for recording a pulse once per propeller revolution. Figure 23 illustrates how the supporting parameters and reference oscillator are mixed with the 16 channels of data for direct recording on four tape tracks.

The primary instruments required for use in setup, checkout, monitoring, and calibration of the data system are:

1. The monitor discriminator package (figure 24) consists of a power supply; a group of four data discriminators with center frequencies of 16, 24, 32, and 40 kHz; and a frequency calibrator for setup of the discriminators. This package is intended to be carried onboard a test aircraft for observation

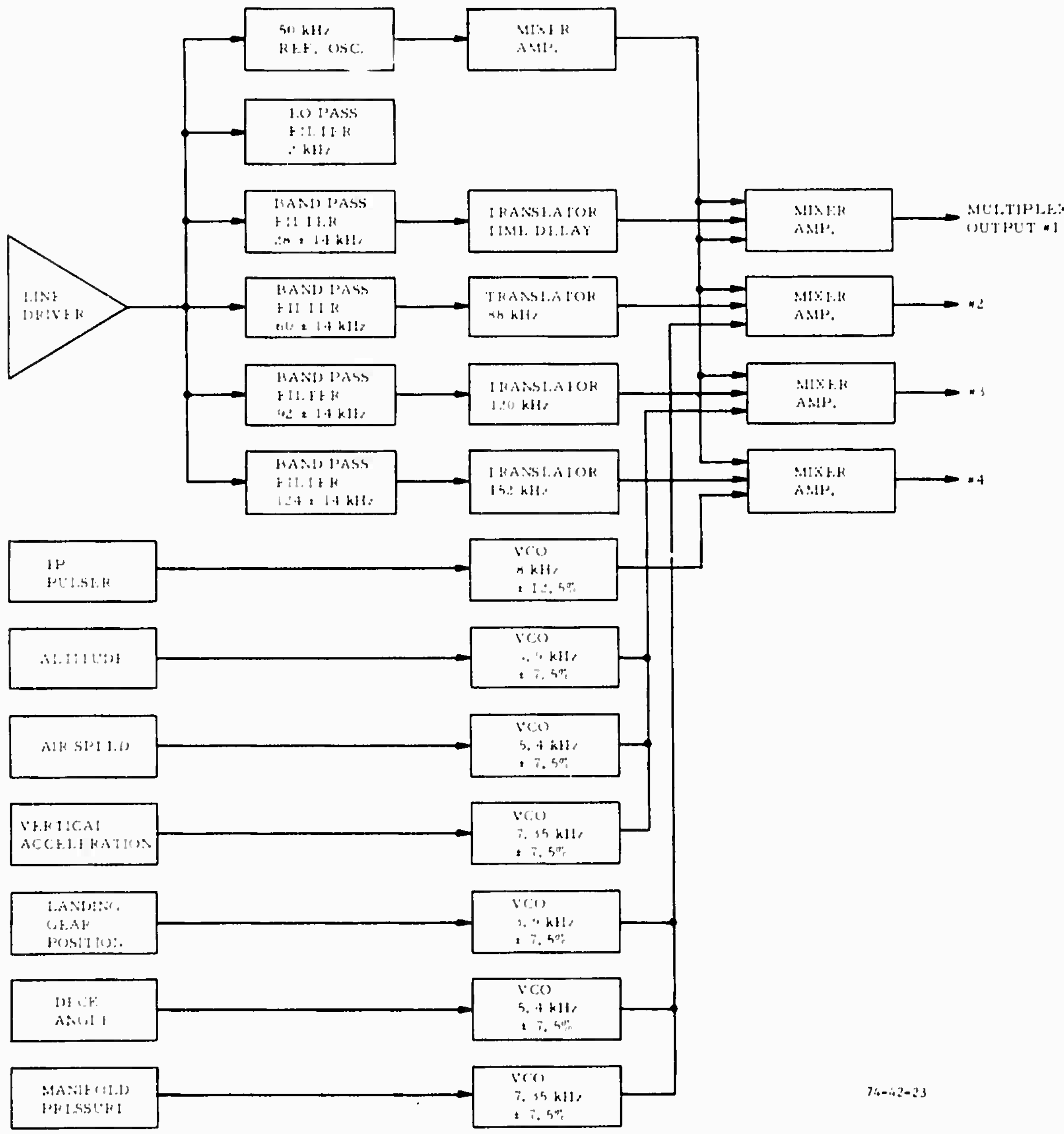


FIGURE 23. AIRCRAFT SUPPORTING PARAMETER UNIT (BLOCK DIAGRAM)

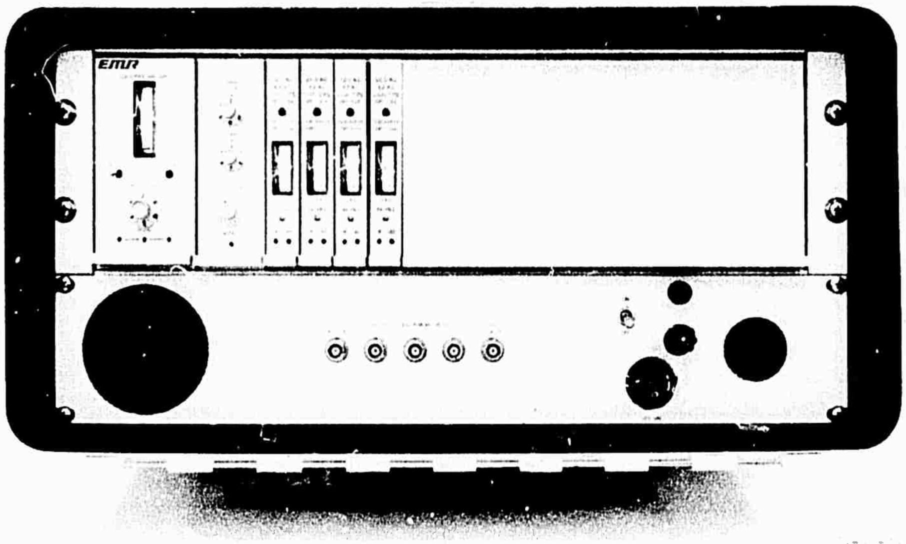


FIGURE 24. MONITORING DISCRIMINATOR EQUIPMENT

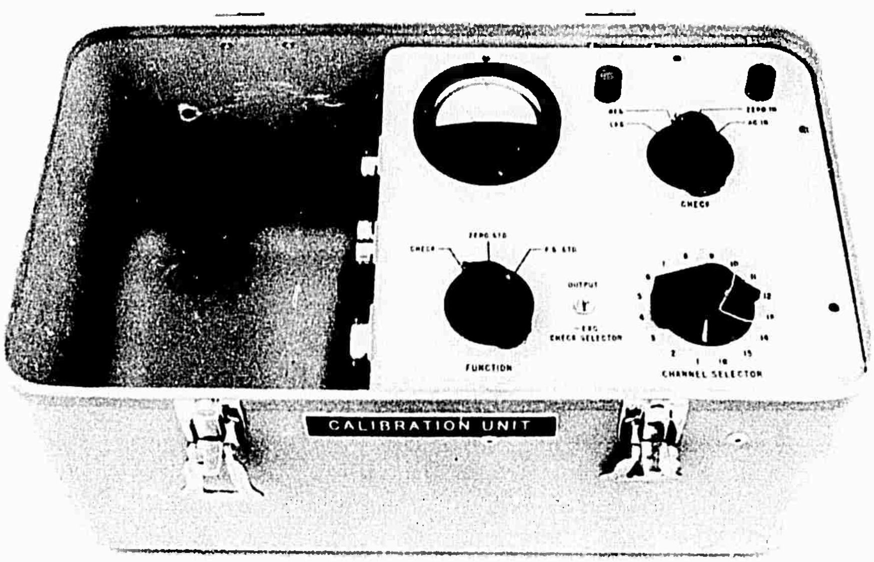


FIGURE 25. CALIBRATION UNIT

of each data channel during system calibration by connecting to the translator package "monitor outputs." The demodulated output of each data channel can also be observed during ground run-up of a test aircraft to observe the system operation with the propeller turning. This package has been designed to tolerate temperature extremes of -20°C to 50°C.

2. The calibration unit is pictured in figure 25. This unit is used for checkout and calibration of the data system when the propeller is not rotating. The calibration unit can be used to check the resistance and leakage to ground of each propeller-mounted strain gage when the function switch is in the check position. In addition, the check function can be used to observe the output from each data channel with the strain gages connected to the data system but without excitation voltage supplied to the gages. Also, the test oscillator can be connected to the terminals (J36) and used to check the frequency response of each data channel.

3. A battery supply is used to provide power to the data system during system ground checks. Mechanical adaptation to new installations require that the structural capability and mechanical impedance of the brackets are suitable to the propeller-engine combination. The primary consideration affecting the rotating components involves the requirement of adequate strength to support the split assembly against centrifugal force. On the other hand, the stationary components are cantilevered from the engine, which makes the stiffness of the brackets a prime consideration.

The rotating members are to be statically and then dynamically balanced prior to actual aircraft installation. The gages and wire on the propeller, when installed with care (wiring one side exactly as the other), should not cause any problems necessitating balancing of the propeller itself. If balancing facilities are available, it is suggested that it be done.

Figure 26 is a representative assembly drawing for the installation of this system.

As noted previously, calibration of the data system is accomplished by use of the calibration unit and battery power supply. System zero is obtained with the strain gages excited and zero strain input. Full-scale standard is obtained by shunting each strain gage with 110 kilohms. The equivalent strain for this shunt can be determined with the following relationships:

The equation for a single active arm strain gage in bending is

$$\frac{e_o}{E_{exc}} = \frac{G_f \varepsilon}{4} \qquad (5)$$

where e_o = bridge output volts

E_{exc} = strain gage excitation volts

G_f = strain gage factor

ε = strain

$$\varepsilon = \frac{\Delta R}{G_f R} \tag{6}$$

where ΔR = the incremental strain gage resistance, which is a result of a strain input to the bridge.

R = strain gage resistance

For the case of a 110 kilohm shunt in a 350-ohm bridge

$$\text{where } \Delta R = R - \frac{R(R\ \text{shunt})}{R+(R\ \text{shunt})} \tag{7}$$

$$\Delta R = 350 - \frac{(3.5)(1.1)(10^7)}{(350+(1.1)10^5)}$$

$$\Delta R = 1.110\ \text{ohm}$$

Therefore, the full-scale standard strain for a single active bending gage:

$$\varepsilon\ \text{std} = \frac{\Delta R}{G_f R} = \frac{1.110}{2.12(350)} = 1496\ \text{microstrain peak} \tag{8}$$

MINIATURE FM TRANSMITTER DATA LINK.

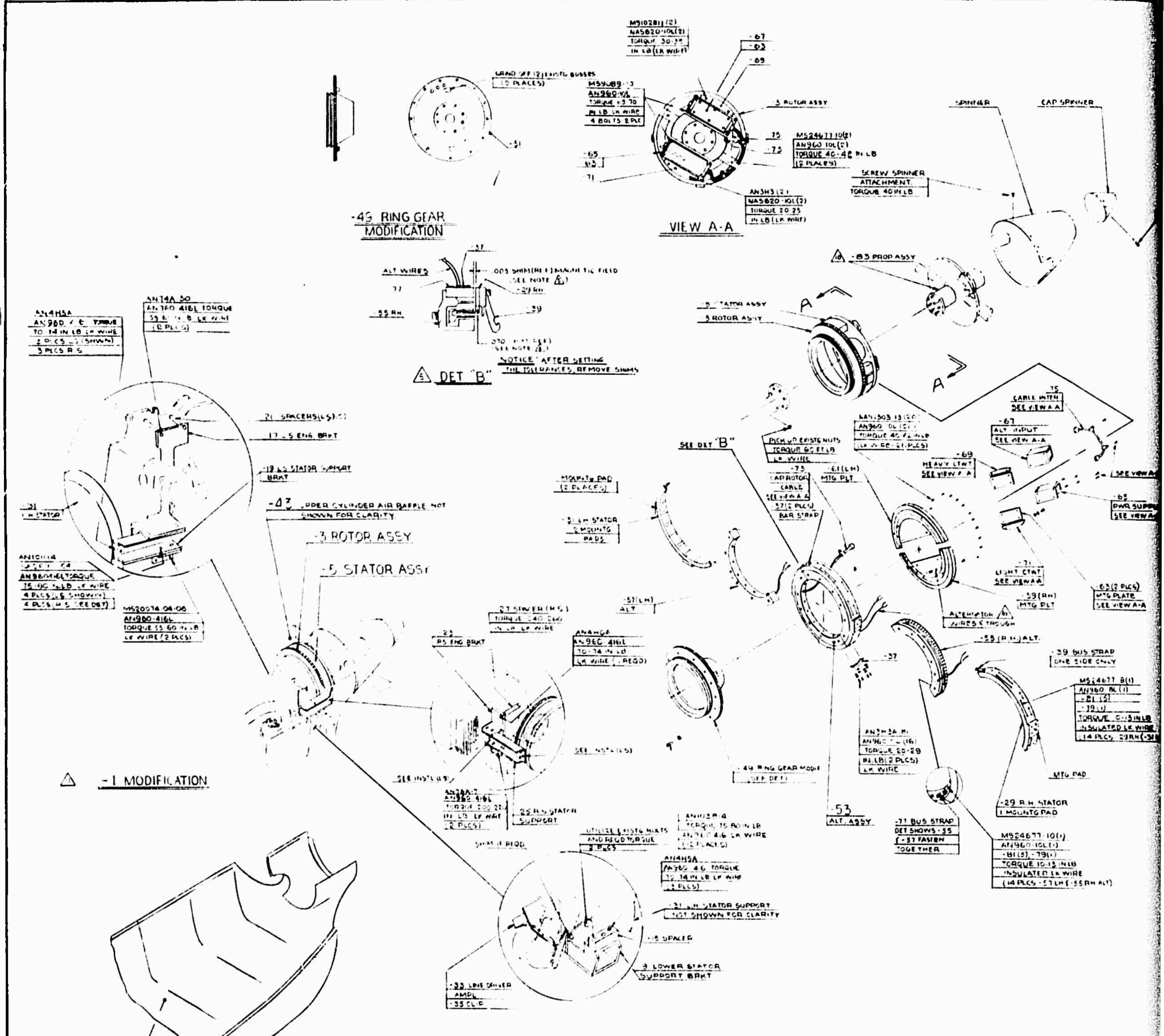
An off-the-shelf, low-cost, reliable FM telemetry device has been tested piggy-backed on a Piper (PA-31) Navajo airplane, the same engine which was already instrumented with the FAA/HSD system. Figure 27 shows this installation consisting of five wireless data coupling (WDC) transmitters and batteries plus the transmitting and receiving antenna. These components are manufactured and sold by the Acurex Corporation, Mountain View, California.

Illustrated in figure 28 are three WDC transmitters and batteries secured to the aft side of the spinner using insulated "Adel" clamps.

An ON/OFF switch with test leads were provided to conserve power as well as to facilitate checking the battery voltage when all the cowling was installed, and a dummy transmitter was used to maintain balance.

The antenna lead from each transmitter was routed to the spinner's aft end and secured around the periphery using insulating standoffs and clamps held by the spinner bulkhead screws. "Ordnance" tape was used to insulate the antenna from the specimen at points between the clamps (figure 29).

Immediately aft of the spinner and attached directly to the forward edge of the cowling, in close proximity to the transmitting antenna, was the receiving antenna. A coaxial cable carried the signal back to the FM receiver (figure 30).



PRELIMINARY INSTRUCTIONS

ALL ROTATING PARTS (-3 ROTOR ASSY) TO BE DYNAMICALLY BALANCED AT 2200 RPM (MAX) PRIOR TO INSTL. ON AIRCRAFT. ASSEMBLE -3 ROTOR ASSY AS PER NOTES 2, 6 & 7.

ASSEMBLY INSTRUCTIONS

1. REMOVE, TAG & STOW THE FOLLOWING EXISTG PARTS, UPPER & LOWER COWLING, UPPER CYLINDER AIR BAFFLE, DEICER BRUSH BLOCK & BRACKET. REMOVE THE CAP SPINNER, SPINNER, RING GEAR & PROP ASSY. PROP ASSY SHOULD BE DEPRESSURIZED & DESLUDGED.
2. FASTEN -57 (LH) AND -55 (RH) ALTERNATORS TO -49 RING GEAR MODIF. CONNECT -77 BUS STRAP AS SHOWN BETWEEN THE SCREW HEADS & TOP SPRING WASHER TO FORM -53 ALT. ASSY.
3. INSTALL ALL -5 STATOR ASSY BRACKETS TO THE ENG (-7 TO -27 INCL.). ALL BOLTS TO BE FINGER TIGHT FOR FINAL ADJUSTMENT. INSTALL -43 MODIF AIR BAFFLE.
4. INSTALL -29 (RH STATOR), -31 (LH STATOR). BOLTS TO BE FINGER TIGHT.
5. INSTALL SHIMS TO ADJUST STATOR CLEARANCE AS PER DET "B". TIGHTEN ALL BOLTS IN -5 STATOR ASSY TO REQD TORQUE. FASTEN -49 RING GEAR MODIF TO -83 PROP ASSY. AFTER SETTING THE .070 AND .005 TOL, REMOVE THE SHIMS.
6. INSTALL -59 (RH MTG PL), FEEDING THE ALT. WIRES (-55 & -57) THRU THE HOLES PROVIDED. SEE -53 & -59. INSTALL -71, -63 & -65.

CAUTION: HANDLE ALT. WIRES WITH EXTREME CARE TO PREVENT BREAKAGE.

7. INSTALL -61 (LH MTG PL), -69, -65, -67, -75, -45 & -47.
8. SEE WIRING DIAGRAM STD DWG 0000260.
9. GROUND TEST ENGINE AT MAX RPM FOR ONE (1) MIN. SHUT DOWN AND INSPECT FOR INTERFERENCE BETWEEN MOVING PARTS.
10. SEE MAINT. MANUAL FOR PROP PRESS. REQRMENTS

INSPECTION

11. CHECK ALL TORQUE REQ'MTS AFTER ASSY

DISASSEMBLY

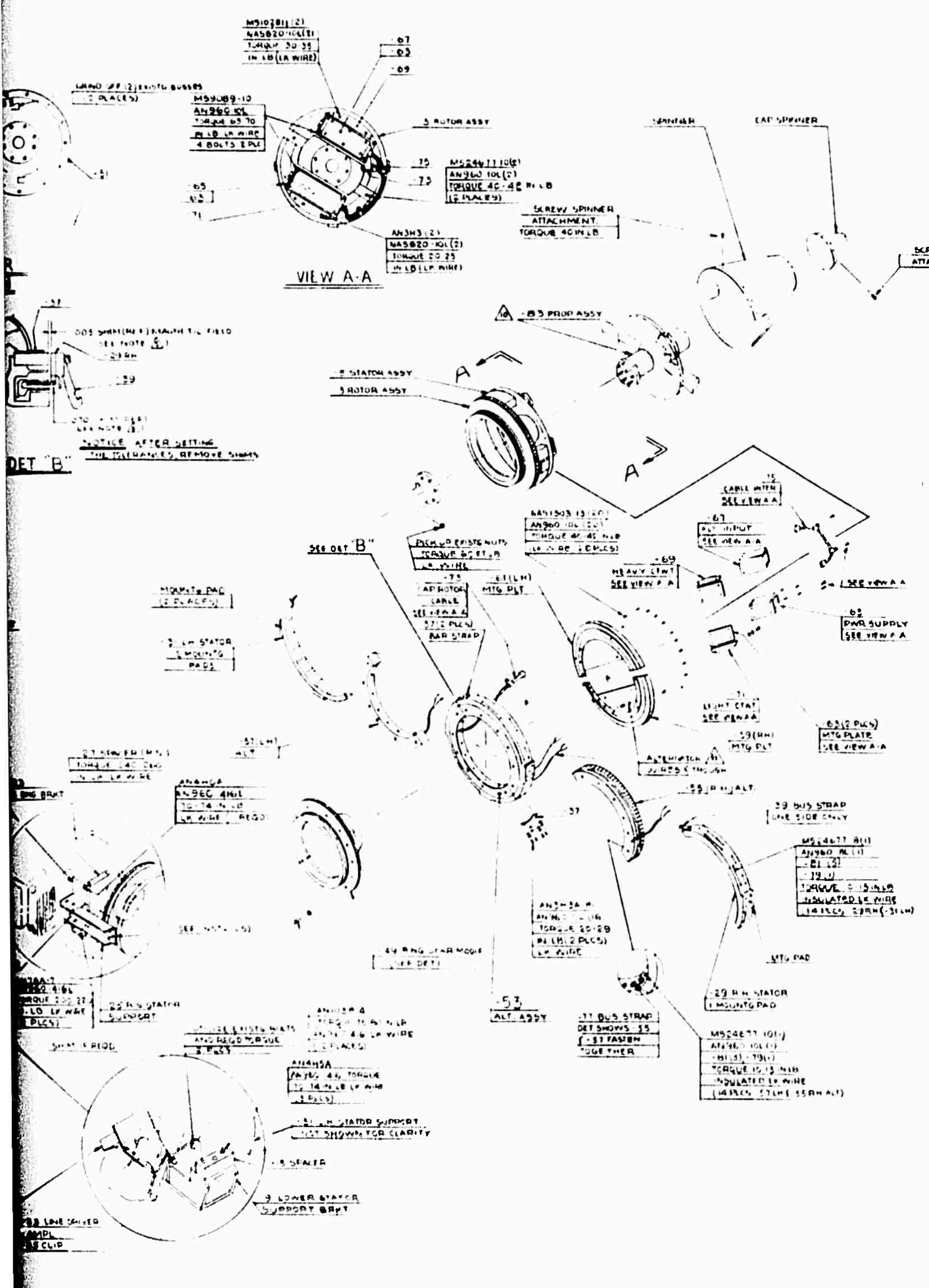
12. ALL PARTS WHEN DISASSEMBLED WILL BE MARKED AND IDENTIFIED BY THERE ASSOCIATED PART NO. AND BAGGED WHERE FEASIBLE [illegible] ACCORD WITH THE BILL OF MAT[illegible]

REF INFORMATION

13. THIS POWER PLANT MODIFICATION WAS COMPLETED IN ACCORD WITH HAMILTON STANDARD REPORT # 1354 DATED 4/67.

FIGURE 26. POWERPLANT MODIFICATION FOR PROPELLER VIBRATION SYSTEM

A	DWG NO. WAS STD223-A431-4



NEXT ASSY	QTY					
-5	20	BOLT		NAS1303-13H		
-5	4	WASHER		NAS620-10L		
-5	4	BOLT		MS20014-04-16		
-5	2	BOLT		MS20014-04-06		
-5	2	BOLT		MS102811		
-3	2	BOLT		MS24678-10		
-5	14	SCREW, CAP, SOCK HD		MS24677-10		
-5	14	SCREW, CAP SOCK HD		MS24677-8		
-5	8	BOLT		MS9089-10		
-5	14	WASHER		AN960-8L		
5	28	WASHER		AN960-10L		
-5	12	BOLT		AN1038-4		
5	4	BOLT		AN76A-7		
-5	8	NUT		NAS679 C4		
5	1	BOLT		AN4H6A		
-5	8	BOLT		AN4H5A		
-5	8	BOLT		AN3H3A		
-5	[illegible]	WASHER		AN960-416L		
			NA 543			
-1	1	PROP ASSY		-83		HAMILTON STANDARD, WINDSOR LOCKS, CONN.
-5	16	SPRING WASHER		-81	[illegible] CORP, BRISTOL, CONN. PT# 80512-01	
-5	16	SPECIAL FLAT WASHER		-79	FEDERAL SCREW PRODUCTS, CHICAGO, ILL PT# 97419	
-53	1	BUS STRAP		-77		HAMILTON STANDARD
-5	1	CABLE INTERCONNECT (ALTERNATOR / PWR SPLY)		-75		
-3	1	CAPACITOR ROTOR CABLE		-73		
-3	1	LIGHT CTWT		-71		
-3	1	HEAVY CTWT		-69		
-3	1	ALTERNATOR INPUT		-67		
-3	1	POWER SUPPLY		-65	SK68758	
-5	2	ELECT. MTG PL		-63	SK68776	
5	1	MOUNTG PLATE (LH)		-61	SK68771-1	
-5	1	MOUNTG PLATE (RH) WITH ALT WIRE TROUGH		-59	SK68771-2	
53	1	ALTERNATOR (LH)		-57	SK68765-2	
53	1	ALTERNATOR (RH)		-55	SK68765-1	
-5	1	ALTERNATOR ASSY		-53		
-83	1	RING GEAR		-51		
-5	1	RING GEAR MODIF		-49		HAMILTON STANDARD
-1	1	UPPER COWLING		-47		WINDSOR LOCKS, CONN
-1	1	LOWER COWLING		-45		
-1	1	UPPER CYL. AIR BAFFLE		-43		
				-41		
-5	1	BUS STRAP		-39		HAMILTON STANDARD
-5	2	BAR STRAP		-37		WINDSOR LOCKS, CONN
-5	1	CLIP		-35		
-5	1	LINE DRIVER AMPL		-33	SK67881	
-5	1	STATOR (LH - 2 MTG PAD)		-31		
-5	1	STATOR (RH - 1 MTG PAD)		-29		
-5	2	SPACERS (R.S.) ENG BRKT		-27	SK68795	
-5	1	STATOR SUPPORT BRKT (R.S.)		-25	SK68792	
5	1	ENG BRKT (R.S.)		-23	SK68793	
5	2	SPACERS (L.S.) ENG BRKT		-21		
5	1	STATOR SUPPORT BRKT (L.S.)		-19	SK68790	
5	1	ENG BRKT (L.S.)		-17	SK68791	
5	1	SPACER, LOWER ENG. BRKT		-15		
				-13		
				-11		
5	1	LOWER STATOR SUPPORT BRACKET		-9		HAMILTON STANDARD
				-7		
-1	1	STATOR ASSY		-5		
-1	1	ROTOR ASSY	NA 543	-3		
0000261		MODIFICATION	NA 350	-1		

5\. INSTALL SHIMS TO ADJUST STATOR CLEARANCE AS PER DET "B". TIGHTEN ALL BOLTS IN -5 STATOR ASSY TO REQD TORQUE. FASTEN -49 RING GEAR MODIF TO -83 PROP ASSY. AFTER SETTING THE STATOR AND ROTOR, REMOVE THE SHIMS.

6\. INSTALL -59 (RH MTG PL), FEEDING THE ALT. WIRES (-55 & -57) THRU THE HOLES PROVIDED. SEE -55 & -59. INSTALL -71, -63 & -65.

CAUTION: HANDLE ALT. WIRES WITH EXTREME CARE TO PREVENT BREAKAGE.

7\. INSTALL -61 (LH MTG PL), -69, -65, -67, -73, -45 & -47

8\. SEE WIRING DIAGRAM STD DWG 0000260.

9\. GROUND TEST ENGINE AT MAX RPM FOR ONE (1) MIN. SHUT DOWN AND INSPECT FOR INTERFERENCE BETWEEN MOVING PARTS.

10\. SEE MAINT. MANUAL FOR PROP PRESS. REQUIREMENTS

INSPECTION

11\. CHECK ALL TORQUE REQ'MTS AFTER ASSY

DISASSEMBLY

12\. ALL PARTS WHEN DISASSEMBLED WILL BE MARKED AND IDENTIFIED BY THERE ASSOCIATED PART NO AND BAGGED WHERE FEASIBLE IN ACCORD WITH THE BILL OF MATL

REF INFORMATION

13\. THIS POWER PLANT MODIFICATION WAS COMPLETED IN ACCORD WITH HAMILTON STANDARD REPORT # 1354 DATED 4/67.

FEDERAL AVIATION ADMINISTRATION
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
ATLANTIC CITY, N. J.

POWER PLANT MODIFICATION
PROP VIBRATION SYSTEM

MIDEVIT T.J.

NA-350 | E | 0000261 | A

502-304-07X

FIGURE 26. POWERPLANT MODIFICATION FOR PROPELLER VIBRATION SYSTEM

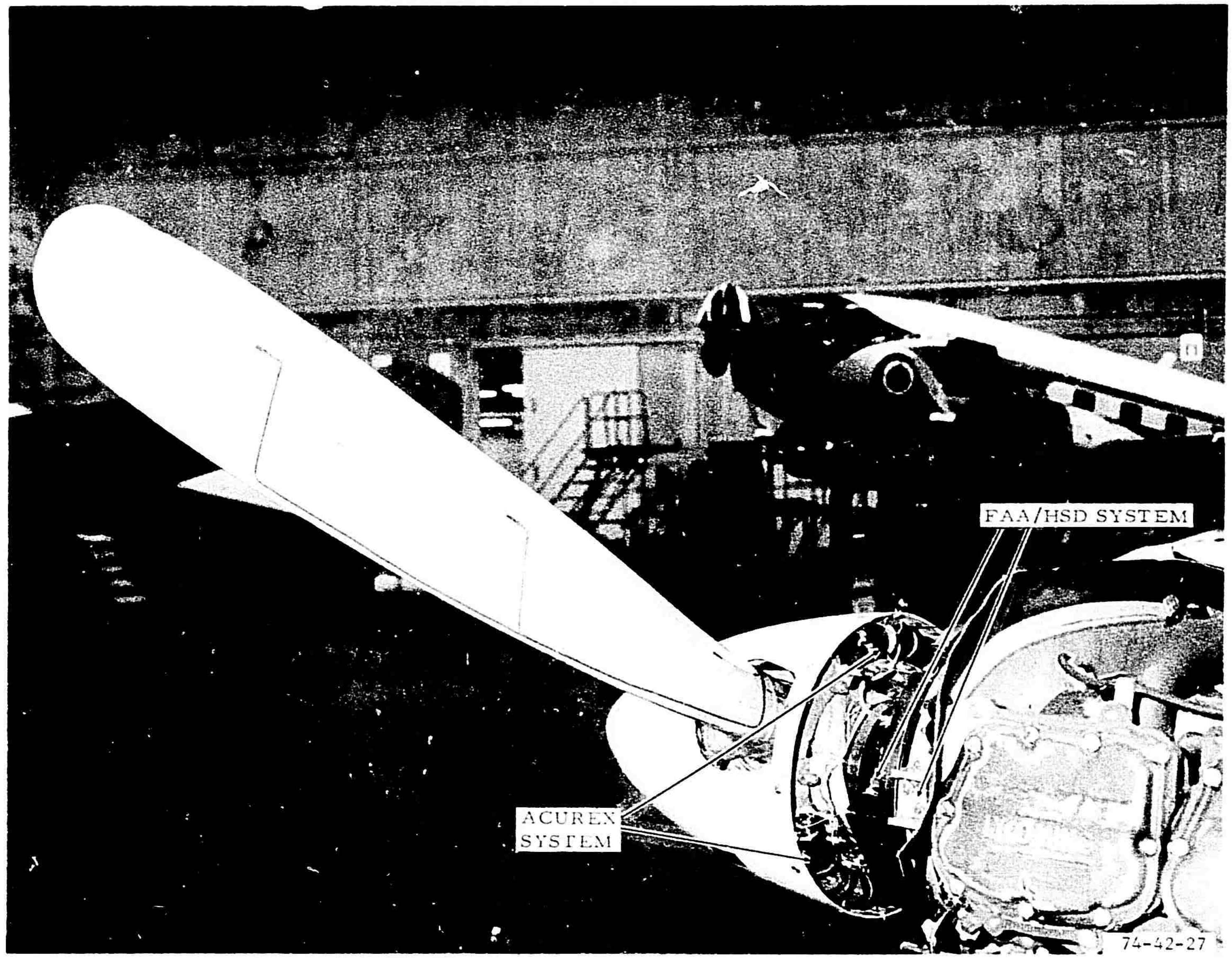


FIGURE 27. FAA/HSD AND ACUREX SYSTEMS INSTALLED

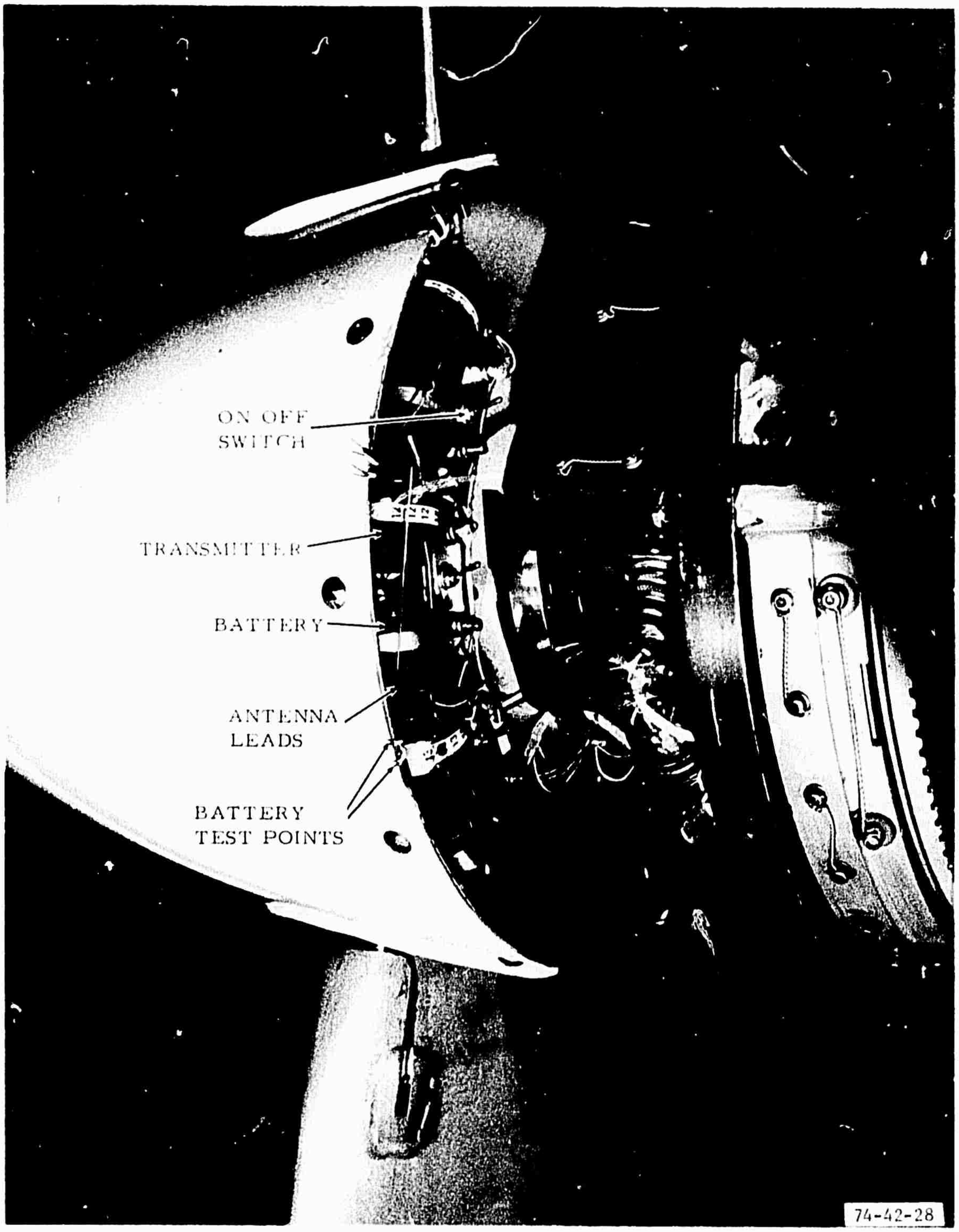


FIGURE 28. TRANSMITTERS AND BATTERIES INSTALLED IN TEST AIRCRAFT

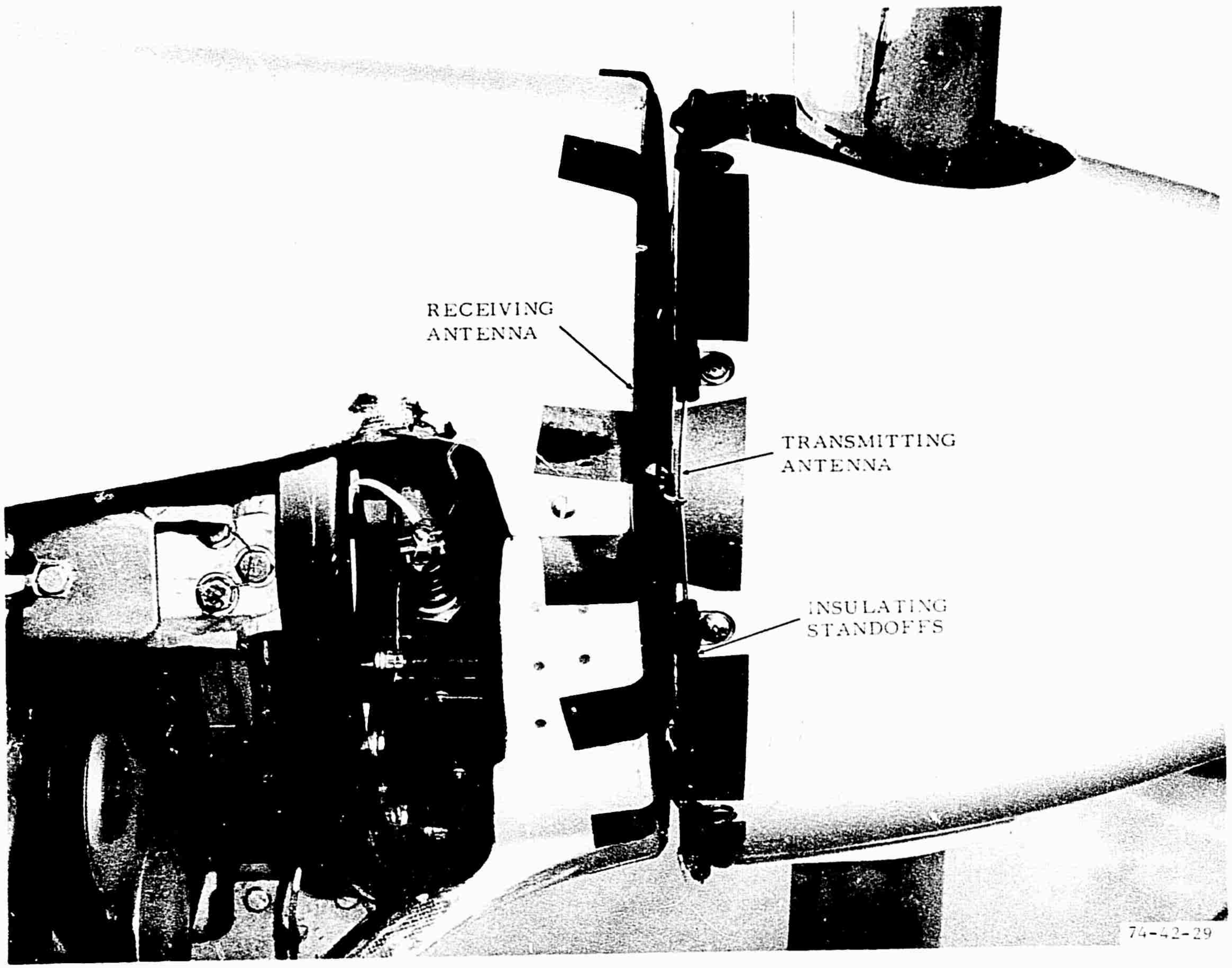


FIGURE 29. ANTENNA INSTALLATION

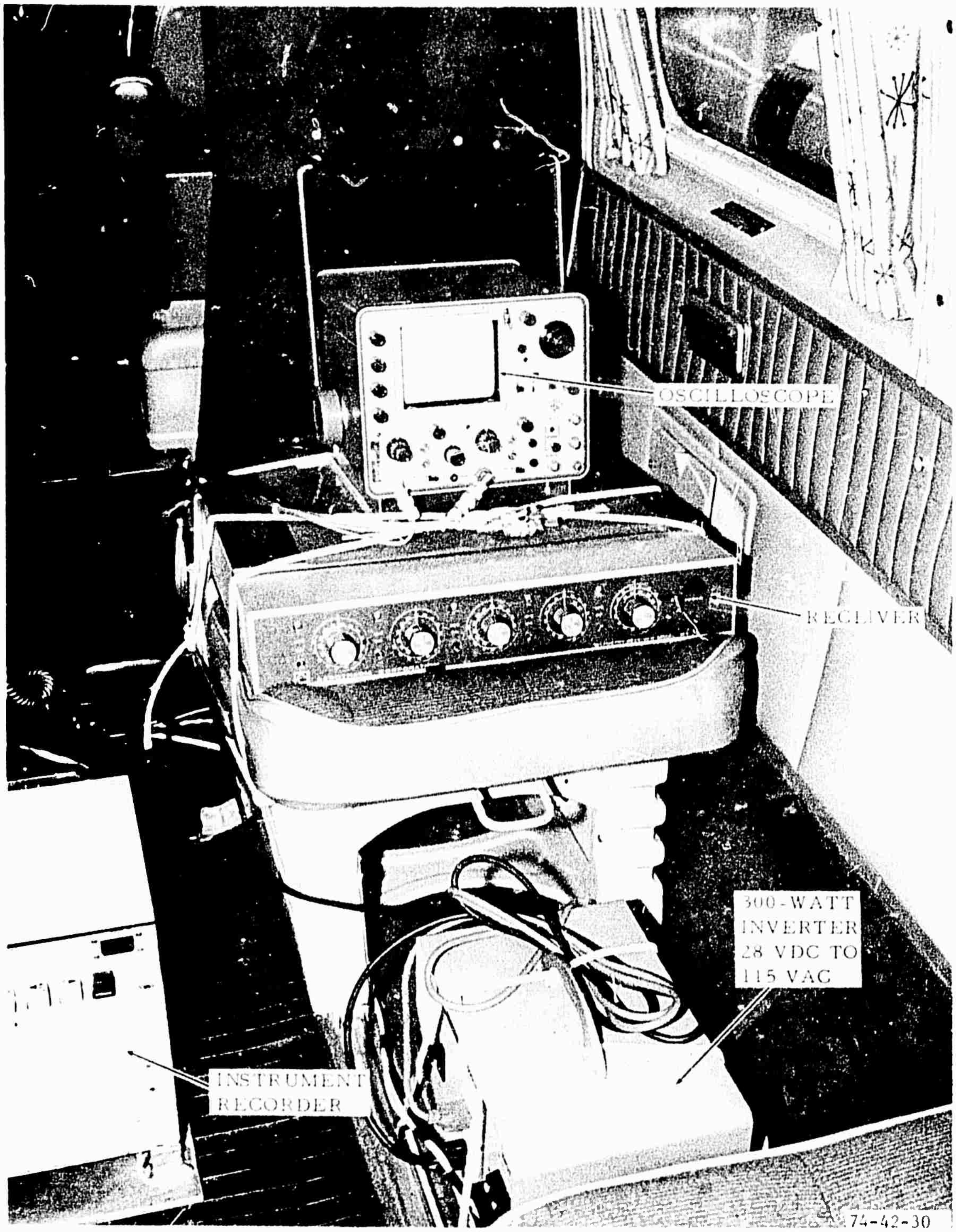


FIGURE 30. EQUIPMENT INSTALLED ABOARD TEST AIRCRAFT

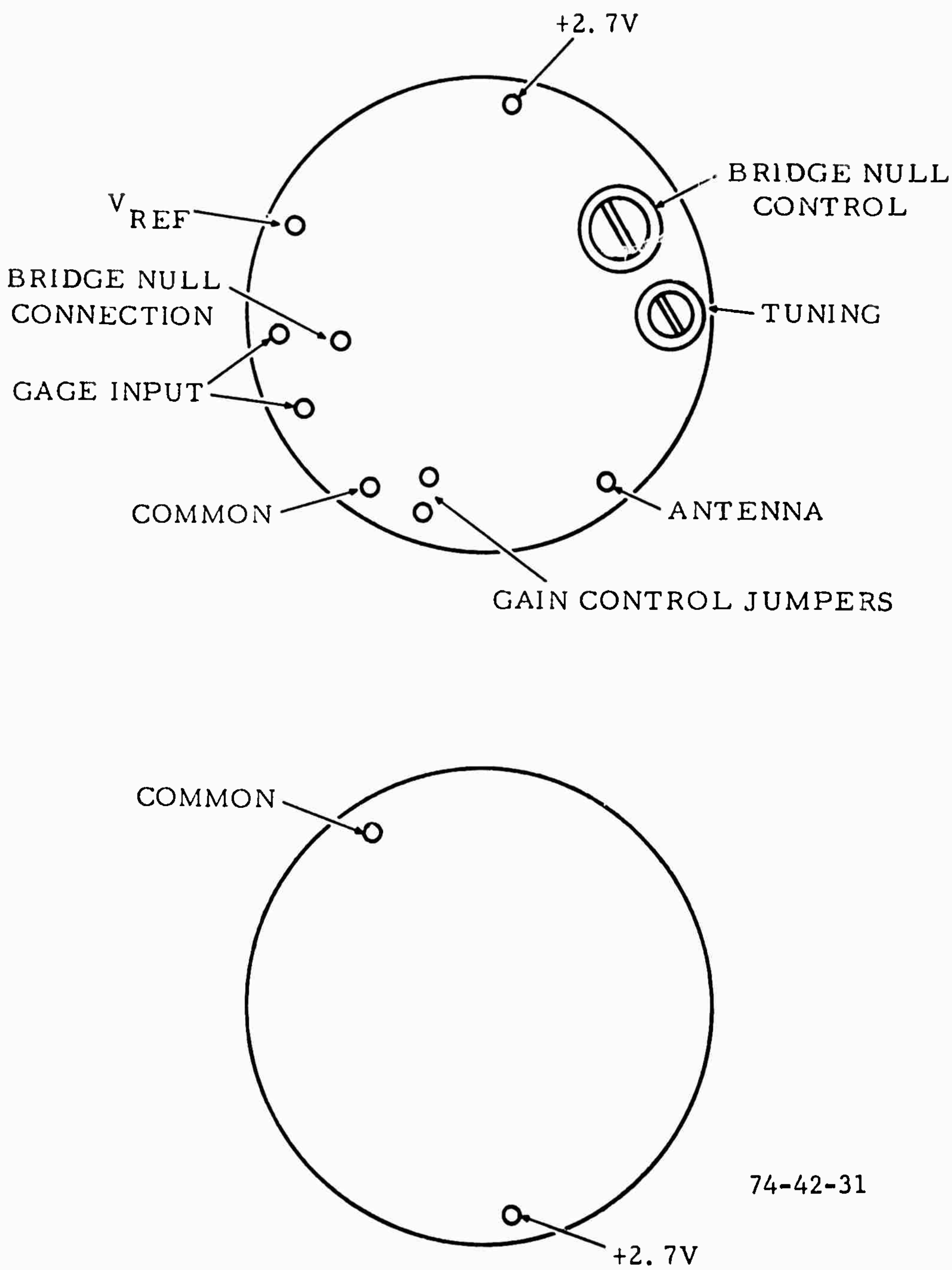


FIGURE 31. PIN ALIGNMENT OF THE TRANSMITTER

The transmitter radiofrequency (RF) signal was demodulated in the receiver and further processed in the signal-conditioning section.

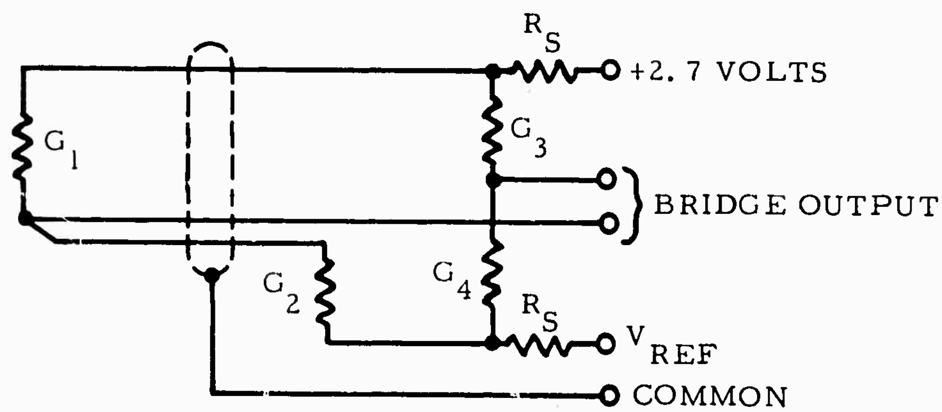
The receiver output then was a true amplified reproduction of the strain gage input to the transmitter and suitable for recording on a standard instrumentation recorder.

A period of familiarization by making a bench test of the WDC system, if possible, is recommended, so system checkout can be easily attained with the actual test article. This bench test will also help in identifying and dealing with possible difficulties.

Since it is not feasible to construct a strain gage bridge without certain variables caused by resistance spread between like gages, hookup connections, lead length, temperature, mounting inconsistencies, etc., the bridge must be "zeroed" out according to the manufacturer's instructions.

Calibration is accomplished by temporarily placing a jumper between the bridge balance and bridge output pin of the transmitter (figure 31).

Figure 32 shows a typical strain gage bridge circuit used with the system.



G1, G2, G3, G4 = 350 Ω

R_S = 175 Ω

74-42-32

$$\text{FULL-SCALE RANGE} = R \times \frac{R_G + 2\,R_S}{R_G}$$

$$= 1500 \times \frac{350 + 2 \times 175}{350}$$

$$= 3000\ \mu S$$

FIGURE 32. STRAIN GAGE BRIDGE

DESCRIPTION OF STRAIN GAGE INSTALLATION TECHNIQUES

Basic requirements must be achieved prior to any attempt for success in the art of strain gage applications. The most important requirements are those of cleanliness, extreme care, attention to detail, and a carefully rehearsed well-thought-out plan of action.

The entire operation of instrumenting a test article requires a number of days. A hospital-like atmosphere is required in which to perform the "operation." A "clean room" or laboratory that maintains a 70° F to 85° F temperature range, has good ventilation, is somewhat dust-free, and has a relative humidity range of 30 to 65 percent is required. Good lighting should be available for the close work involved. Also needed are a couple of clean, sturdy work tables on which to spread out the equipment and material. A wash basin should be nearby, equipped with soap, hot, and cold water with which to scrub up before, during, and after the cleanup work.

The test article itself must be on a stand that allows access to it from all sides. A workstand on full castor wheels and high enough so that the test article is at a comfortable standing work height should be available. The workstand needs a small top to hold the instruments required during a particular phase of the operation. A nominal top size of 24 by 30 inches is the most practical. The propeller hub is mounted vertically in the center so that the camber side of the blade is up and the blade face down. Clean paper is used on this top and is changed as it becomes contaminated.

Many strain gage manufacturers are available. General Services Administration (GSA) carries a schedule of manufacturers supplying the variety of specialized instruments, materials, and the strain gages required to conduct stress/strain propeller tests. For purposes of clarity and simplicity, the text of this report will refer to just one, Micro Measurements, a Division of Vishay Intertechnology, Inc. Other necessary items can be procured through local or GSA sources.

Basic tools are included in kit form from Micro Measurements in their Master Strain Gage Application Kit MAK-1. Briefly, the kit contains surface preparation materials and chemicals, special adhesives, a temperature-controlled miniature soldering iron and special solder, a variety of application tools--such as scalpel, surgical shears, tweezers, and dental probes and cutters--hardware, and still other items needed for the operation (figure 33).

A reliable technique used for preparing an aluminum alloy, such as a propeller, begins with a complete and thorough degreasing and paint-removal process using methyle ethyl ketone (MEK) as the final cleaning agent.

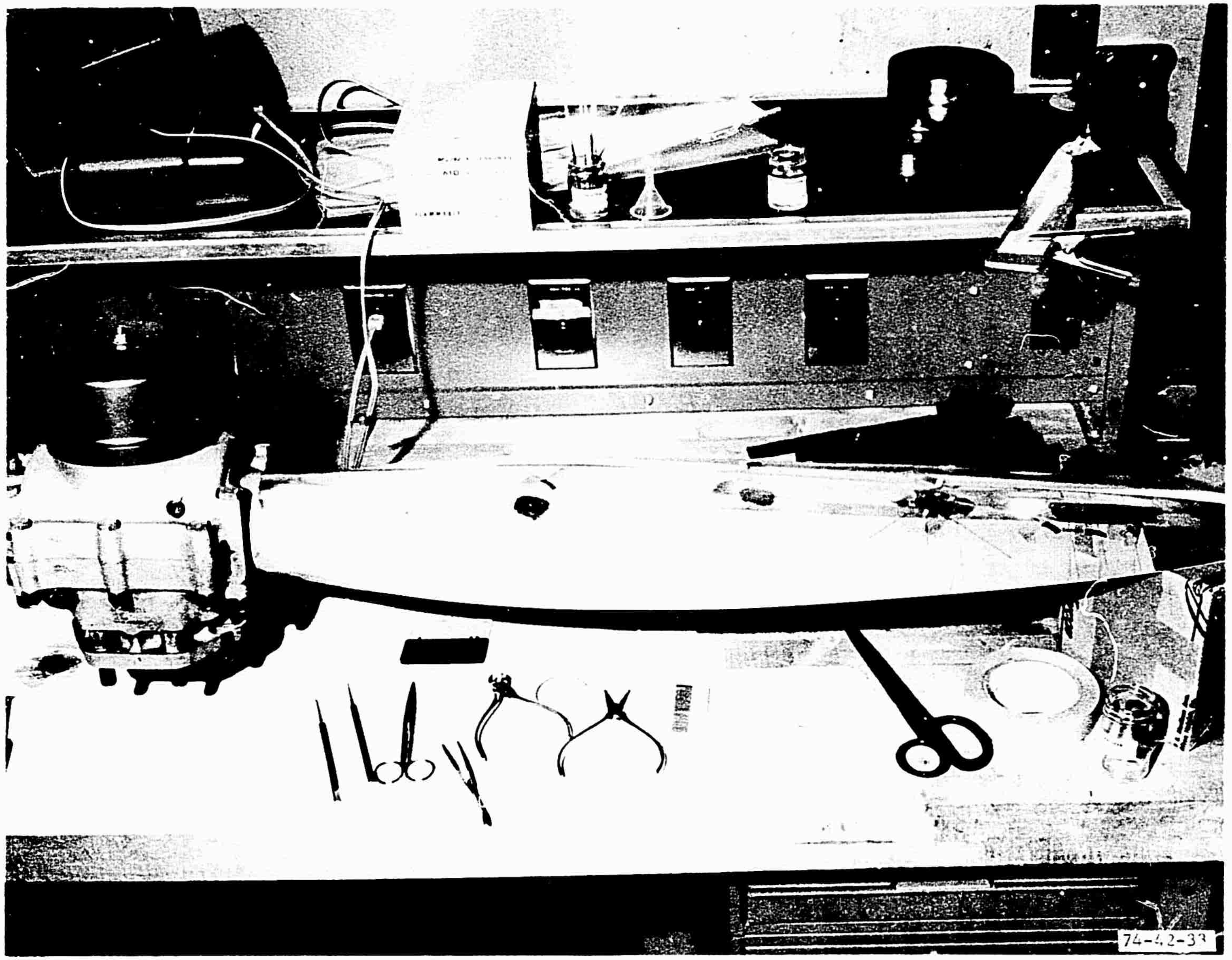


FIGURE 33. STRAIN GAGE APPLICATION EQUIPMENT

To prevent contaminants from entering the test area the first step is not done in the "clean room." Degreasing of the propeller is done by steam or reliable chemical degreasers. The degreasing process is followed by a thorough clean-water rinse, and then the test article is dried with a clean cloth, followed by a rubdown with MEK. Very careful attention is given to the gage areas and the route that the wiring will follow.

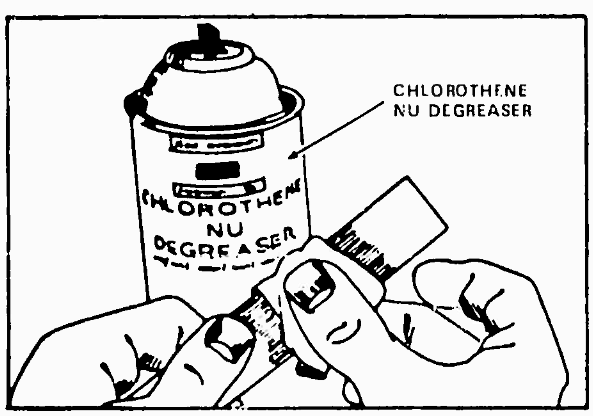
Safety rules and precautions that are consistent with good industry practices must be followed when handling any of the prescribed materials or chemicals.

The clean, dry test article is then taken from the degreasing area and placed on a workstand in the clean room. Hands are washed with a mild castile soap and rinsed clean. Use of hand creams or other cosmetics that may contain contaminants, such as silicons, which can ruin the clean surface and be very hard to remove from the test article, are meticulously avoided.

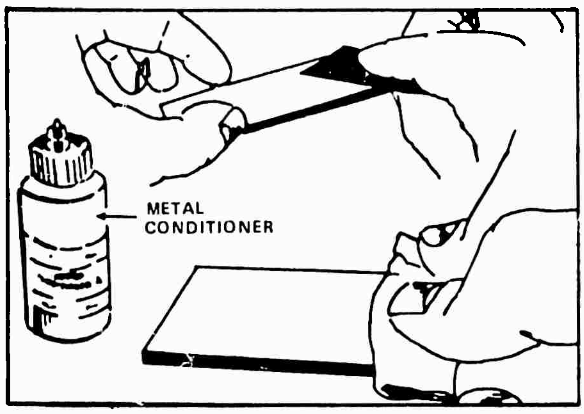
SHORT-TERM MODERATE TEMPERATURE SYSTEM.

The procedure used to "strain gage" a propeller to endure in most weather extremes with a temperature range of -50° F to +150° F is achieved with the use of a cyanoacrylate adhesive (selected Eastman 910). First a determination is made for the location of each strain gage on the test article. An area approximately 2 inches in diameter is prepared to receive the strain gage.

The 2-inch area is outlined with a 2B (graphite) pencil and further prepared prior to the actual strain gage application. The gage area is sprayed with chlorothene NU, swabbed, and then dried with 2- by 2-inch cotton gauze sponges. Each sponge is handled so as not to touch the gage area with any part of the sponge that comes in contact with the fingers or other contaminants.



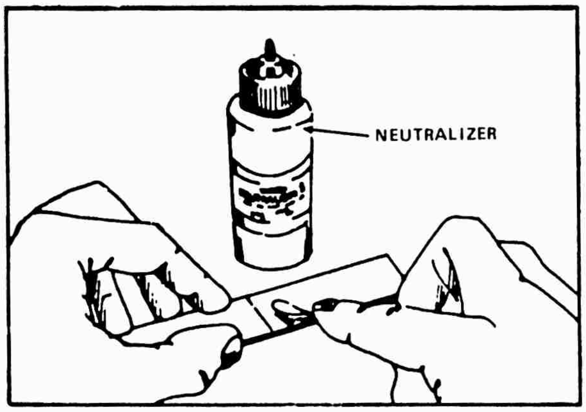
Wet or dry silicon-carbide sandpaper, 400 grit, cut to 2-inch lengths, is dipped into the M-prep metal conditioner, and with pressure from the edge of the finger, any plating or Anodize from the 2-inch diameter is sandpapered off in a back and forth motion, being careful not to allow the conditioner to air dry. The sandpaper is redipped into the conditioner as required to keep the lapped surface wet.



This area is then carefully sponged dry with a single slow, but firm, stroke so as not to drag contaminants into the gage area from adjacent areas. A fresh sponge is used each time for each stroke until dry. The gage area is then closely examined with a four-power magnifying glass, followed by repeating the lapping and drying operation. The surface should appear brighter and cleaner upon reexamination with the four-power glass.

A wooden handle, cotton-tipped applicator, dipped into the M-prep metal conditioner, is used to buff the gage area. Two or three cotton-tipped applicators for each gage area are used until discoloration of the applicator is evident, and then it is sponge-dried immediately.

A 4H lead pencil point is used to burnish onto the gage area any alignment marks necessary to pinpoint actual gage location. This is followed with a cotton-tipped applicator dipped in M-prep neutralizer using generous amounts and swabbed over the gage area. The area is sponge dried using the same technique, a single, firm, slow stroke. The swabbing and drying process is then repeated.



An applicator is never dipped into the neutralizer more than once, and the applicator is immediately discarded after use. The same routine is followed for the sponges. One sponge at a time is taken from its package, it is used once and thrown away. The sterile sponges come in a paper package; while opening this package, care is taken so that only one sponge at a time can be dispensed, while the others remain inside the package protected from contamination. A "water-break test" of the gage area indicates fairly accurately whether or not the surface is ready to accept the adhesive. A drop of clean tap water is placed on the wooden end of a cotton-tipped applicator and touched to a portion of the prepared gage area. If the droplet immediately spreads out and "wets" a large area, the surface is properly prepared. Surface tension is broken, which allows the water droplet to "lay" in a very thin line.

The same action takes place when the adhesive is applied. A thin glue line is extremely important in order to achieve intimate contact between the gage and the specimen. The glue line is approximately 0.0016-inch thick (nominal). It is necessary to repeat the neutralizer swabbing and drying step to remove the water from the gage area after the water-break test.

At that point, when all the gage areas are ready to receive the gages, a general cleaning of the work areas is undertaken to remove all metal conditioners, sandpaper, etc.

A nearby work area should be made ready to tape a 6- by 6-inch piece of plate glass down onto a clean paper-covered table top. The instruments for handling the strain gages, such as tweezers, dental probes and scalpel, are all cleaned in neutralizer, dried, and placed in position for use. All bottles are capped except when in actual use, as the neutralizer fumes adversely affect the adhesive. Hands are washed with mild castile soap, rinsed well, and dried.

Two types of strain gages suitable for this type of installation are the WK-12-250 BG-350, Option "W," and the WK-13-250 RA-350, Option "W."

These "WK" gages are fully encapsulated KARMA alloy, designed for widest temperature range and having the most extreme environmental capability of any general-purpose, self-temperature compensating gage. Option "W" restricts both fatigue life and maximum operating temperature range to an extent, but still allows sufficient latitude to fulfill the requirements between the -452° F to +550° F temperature range. The fatigue life cycles are 10^6 Hz at plus or minus 2,400 microstrain.

The benefits of option "W" provide an integral printed circuit terminal polyimide encapsulated with a portion of the tabs left exposed for ease in soldering. Gage installation time is greatly shortened in most cases and simplified. Simplifying the installation procedure lessens the chance of system failure due to induced human error.

In this same vein, the cyanoacrylate adhesive selected for ease of application is M-Bond 200. This is an excellent, fast-curing, room-temperature adhesive with a normal operating temperature of -50° F to +150° F. There are other compounds that are superior, but, in using them, the installation procedure becomes very involved. The latter should be used only if the tests are to be for an extended time period. That type of procedure is described later in this section.

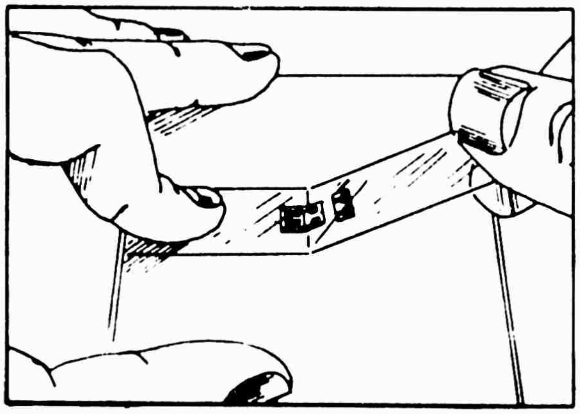
When properly applied, for use in a moderate temperature environment, M-Bond 200 is serviceable for up to 1 year. M-Bond 200 is hygroscopic, even after it has cured. For this reason, the cap is always on the bottle except when actually applying the adhesive. The cured adhesive bond is also shielded from moisture by a protective coating.

Normal shelf life of M-Bond 200 is 9 months which can be extended if the unopened material is kept refrigerated at +40° F. Due to condensation, the unopened bottle must return to room temperature prior to opening for use and must not be refrigerated after using. M-Bond 200 is a modified methyl-2-cyanoacrylate compound, and measures must be taken to avoid breathing the vapors or skin contact. A single drop squeezed between fingers can instantly bond them, requiring possible surgery to free them.

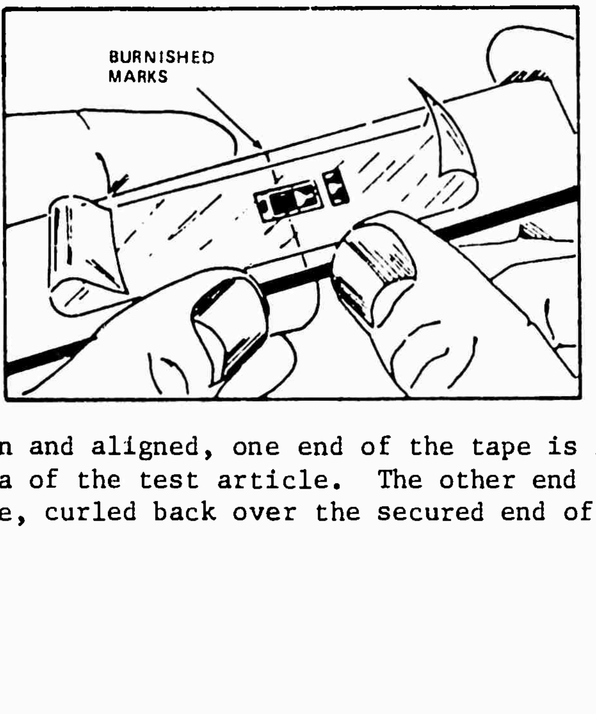
The first gage to be installed from the acetate envelope is removed using only the chemically-clean tweezers and placed on the chemically-clean glass plate, the bond side of the gage is down, and the bright shiny solder tabs are up.

Dental probes are used to align the gage by pushing it into position, and extreme care is used in working the tools so as not to damage the gage.

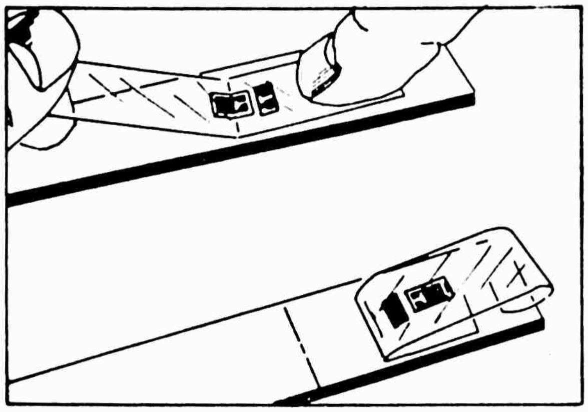
A 5-inch length of 3M cellophane tape (number 157) is positioned lengthwise just above the gage, and then the right thumb and index finger are used to bring the tape down to touch the glass. Static electricity can cause the gage to "jump" off the glass onto the tape. If that happens, the gage may be pulled off with tweezers and replaced on the glass. Once the gage is in place, the tape is pressed down onto the glass in a sweeping motion so that no wrinkles are made and care is taken not to wrinkle the gage or tape. The gage is now firmly stuck to the tape fairly close to center, equidistant from the tape edges.



This tape serves as a handle with which the gage is transported. It is done by carefully lifting one end of the tape, grasping it firmly between index finger and thumb, and proceeding to lift the tape and gage. As the tape is smoothly lifted (in a single motion), a 30° angle is maintained between the tape and glass so as not to cause a sharp bend in the gage. With one end of the tape in each hand, the gage tape assembly is brought to the previously prepared gage location on the test article. Aligning the triangular gage marks with the burnished marks on the gage area, and the solder tabs of the gage pointing toward the propeller hub, one end of the tape is touched to specimen surface and the remaining tape is secured with a wiping motion.



Once the gage is down and aligned, one end of the tape is left secured outside the gage area of the test article. The other end is then lifted from the test article, curled back over the secured end of tape, and stuck to the test article.

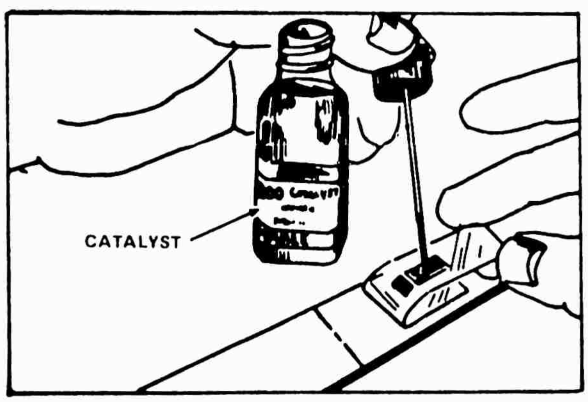


The gage is now upside down atop a flattened loop formed by the curled tape. Eventually, the tape is uncurled and the gage is pressed down to the test article with the gage markings correctly aligned to the marks on the test article.

The gage bonding surface can be cleaned with a cotton-tipped applicator, slightly moistened in neutralizer, if contamination is suspected at any point in the application procedure.

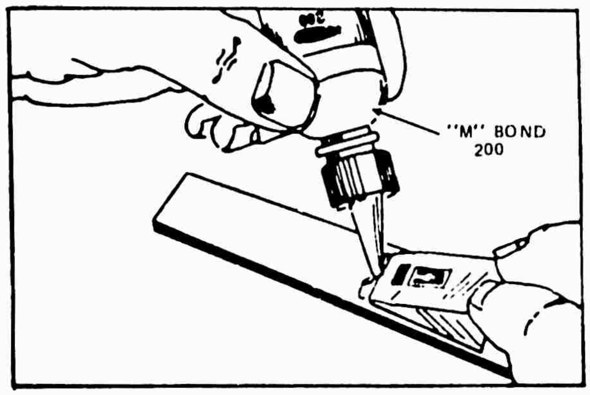
M-Bond 200 catalyst is then applied to the bond surface of the gage. M-Bond 200 adhesive will harden without the catalyst, but not as quickly or as consistently. Very little catalyst is needed and it must be applied in a very thin uniform coat. This is done by lifting the brush cap out of the bottle and wiping the brush against the bottle lip approximately 10 wipes to wring out most of the catalyst.

The brush is then placed onto the gage and swabbed back and forth covering the entire gage WITHOUT LIFTING THE BRUSH FROM THE GAGE. After the gage bond surface is covered, the brush is removed by sliding the brush off the gage onto an adjacent area of tape, and then off the tape and into the bottle. Under normal atmospheric conditions the catalyst will dry after 1 minute.



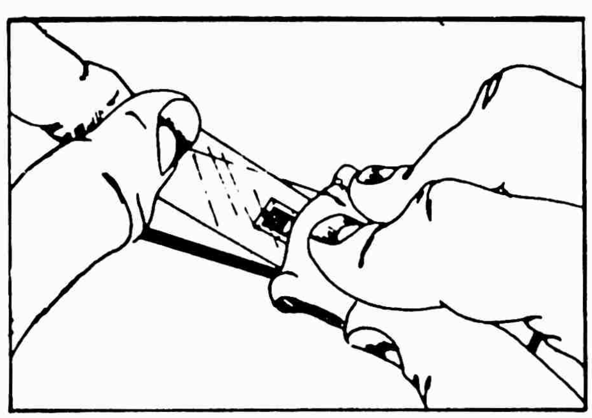
The following steps must be completed in rapid succession:

1. The end of tape that is last curled back and stuck onto the specimen is lifted, while the tape is kept slightly taut and at a 90° angle to the specimen, two drops of M-Bond 200 are placed at the point where the sticky side of the tape contacts the specimen surface. These two drops should be one-half inch from the actual gage location.

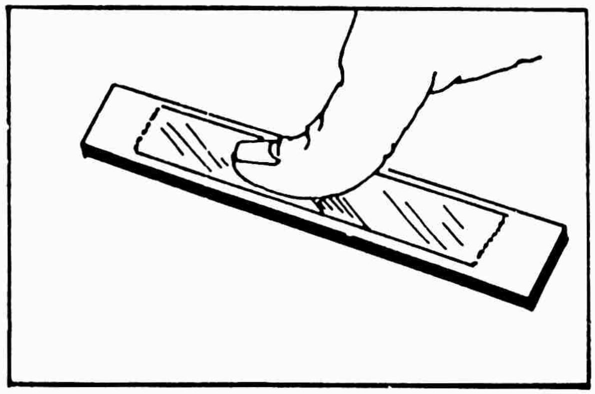


The spacing will ensure that the local polymerization that began taking place as the adhesive came in contact with the specimen surface will not cause unevenness in the gage glue line.

2. Immediately, then, the tape is rotated to a 30° angle, with the gage and tape bridged over the gage area. While still holding the tape taut in the left hand, a sponge, held between the right thumb and index finger, is used in a slow, steady, firm, single stroke. The gage tape assembly is wiped squarely down to the specimen surface over the alignment marks. A very thin, uniform layer of adhesive is desired for optimum adhesive bond performance.



3. Within 1 second after contact with the adhesive, firm thumb pressure must be applied to the gage. This pressure must be held for at least 1 minute. Thumb pressure and heat tend to speed polymerization.

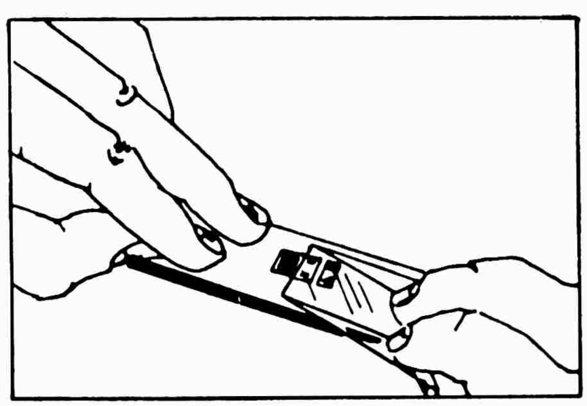


The gage is now solidly bonded in place, and so may be the thumb. If it is, pressing down and twisting the thumb will break the bond with no harm to the thumb. In order to avoid this, a small soft formable pressure pad may be placed between gage-tape assembly and the pressure finger. Bond strength continues to increase rapidly for a period of several minutes after thumb pressure is released, therefore, the tape must remain in place for several minutes longer.

All the events, from the moment the M-Bond 200 is applied, must be accomplished in very rapid succession without any fault; all gages have to go down in as much the same condition as the rest.

The tape can be left in place until ready to make electrical connections, as the tape does afford mechanical protection for the gage.

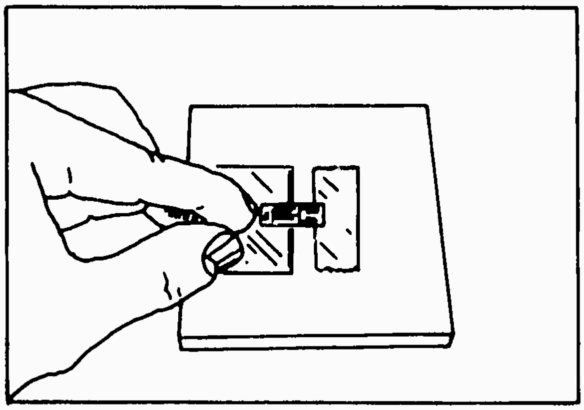
To remove the tape, one end is lifted and peeled back over itself slowly, but steadily, at an oblique angle. When this has been accomplished, the gages are then ready for solder to be applied to their integral solder tabs.



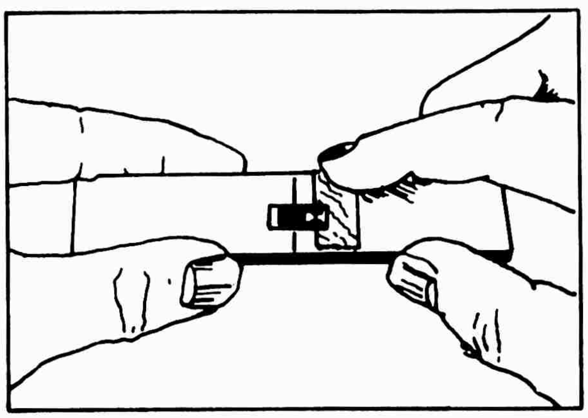
LONG-TERM ELEVATED TEMPERATURE SYSTEM.

A long-term system using specially formulated epoxy resins can be achieved with the use of M-Bond 610. This is a two-part epoxy that must be carefully mixed according to the instructions prior to using.

The gage, when removed from the acetate envelope with tweezers, is placed onto a glass plate and then held in place with the acetate envelope until a piece of Mylar tape is placed halfway over the soldered terminals at the end of the gage.

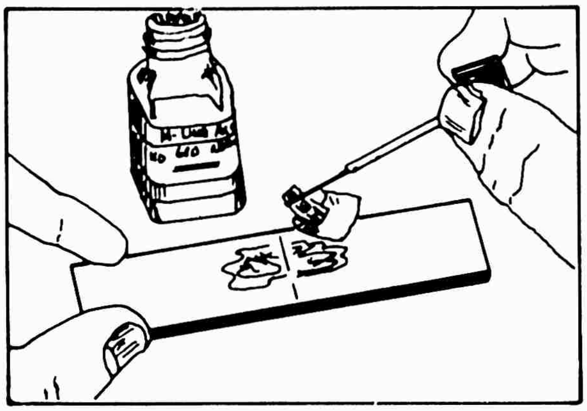


The Mylar tape will allow the gage to be picked up and placed over the alignment marks on the specimen.



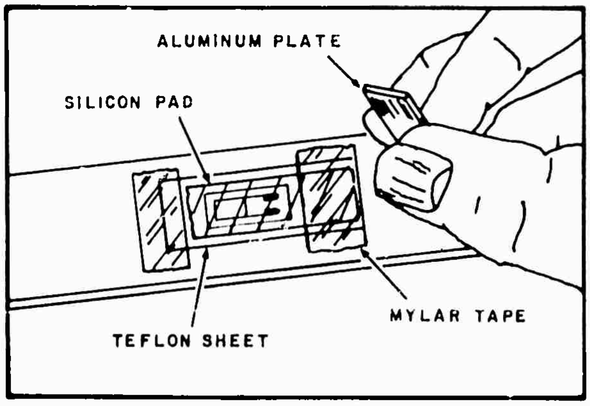
Once this procedure is accomplished, the gage is peeled back again, at a shallow angle, and curled back onto itself so it will remain in position, ready to be replaced onto the specimen alignment marks.

When all gages are in position (figure 33), the adhesive is applied to the gage backing. The adhesive must not come in contact with the mastic on the Mylar tape.



Five to 30 minutes are required for the adhesive to air dry, depending on room temperature and relative humidity, which are kept to 75° F and 50 percent, respectively.

The gage assembly is replaced to its position over the previously made alignment marks. At this point, only enough pressure to tack down the gage is used. Then a thin sheet of teflon is placed over the gage and held in place with a piece of Mylar tape. A 3/32-inch-thick silicone gum pad is placed over the gage, which is in turn covered by an aluminum backup plate of equal size. This entire assembly is held in place with still another overlay of Mylar tape.

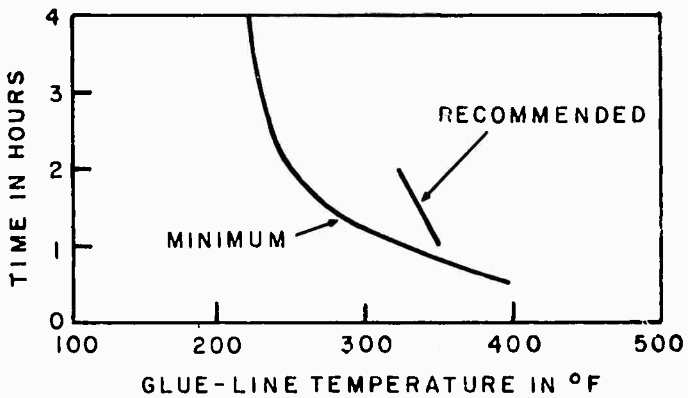


The previously mixed M-Bond 610 has a pot life of 4 hours, so all gages have to be ready for clamping and heat curing within that time.

Clamping, or the application of 15 to 70 pounds-force per square inch (lbf/in^2) pressure, is necessary during the heat cure time. The problem involved during this portion of the process is in applying this pressure and maintaining it equal and steady on all the gages. This is difficult due to the irregular shape of the propeller. This may be overcome by fabricating a polyethylene bag or sock to be slipped over each blade. The bag should be sealed around the blade and then connected to a vacuum source of 25 to 28 inches of mercury, thus providing approximately 12 lbf/in^2 pressure. To allow entrapped air pockets and the adhesives vapors to escape from under the plastic envelope, some strips of 3M Scotch Brite or similar material should be placed near each gage making a path to the vacuum source.

This entire assembly is then placed into a room temperature oven (figure 34). The temperature is elevated at a rate of 5 to 20 degrees per minute, maximum. This allows the adhesive to spread evenly, allowing any residual solvents to escape leaving a thin glue line free of "bubbles."

The time and temperature the specimen is subjected to can be derived from the chart below:



M-BOND 610

RECOMMENDED CURE SCHEDULE

M-Bond 610 is kept in the oven for an additional 2 hours, maintaining a temperature of 75° F above the maximum operating temperature expected for post-curing.

After post-curing the adhesive, the oven is allowed to cool no faster than it was heated.

When room temperature of the specimen is achieved, the vacuum bag, backing plate, silicon gum, teflon, and Mylar tape are removed so that each gage can be closely inspected with a four-power glass.

Upon a satisfactory inspection, the gages are ready for the next process.

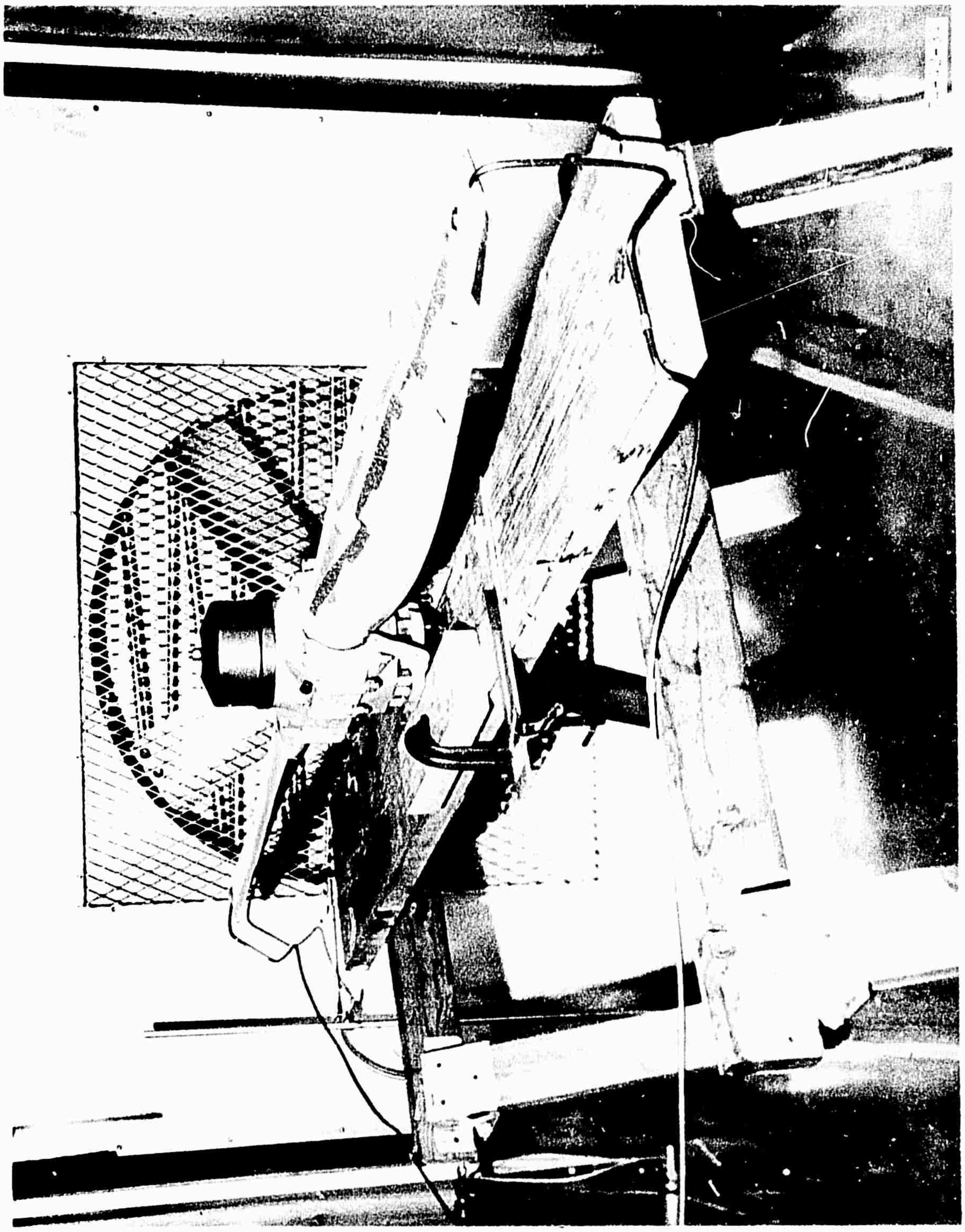


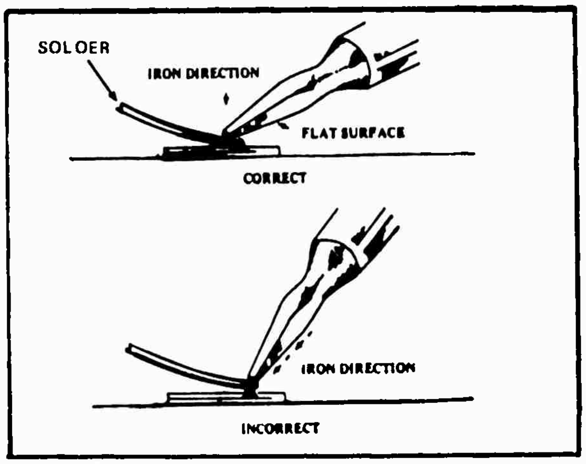
FIGURE 34. HEAT CURE OF EPOXY ADHESIVES

SOLDERING, HOOKUP LEADS, AND FINISH COATS.

A solder known for its excellent wetting and flow characteristics is Type 361-20R. It has high electrical conductivity, good corrosion resistance, and very good mechanical strength. The solidus/liquidus temperature is 361° F, with an activated resin flux core. Overall diameter is 20 mils and is made up of 63 percent tin and 37 percent lead. Solder not specifically designed for strain gage use must never be used.

The soldering iron control is set so that the iron can readily melt the solder and yet not instantly vaporize the flux. Excessive temperatures would "dirty" the iron. Too cool an iron would result in "cold" brittle joints.

While a length of solder is held in one hand and the iron in the other, the solder is brought to touch the spot where it is to be applied, followed immediately with the iron. The technique is to touch the solder first, then the iron, and then take them off in one quick motion. The angle at which the iron is held is fairly flat to the working surface. When the operation is completed successfully, a well-formed solder dot will remain.



Test for sharp points, which indicate that insufficient flux was used, by rubbing the index finger over the solder dot. If the mound did not "wet" onto the surface, insufficient surface preparation can be the reason, and this can readily be seen with a four-power glass.

When all the tabs have had solder mounds applied, they are flushed clean with a rosin core remover and a brush.

The next step involves attaching suitable electrical conductors from the solder tabs, aft, toward the blade trailing edge, and then inboard along the edge to the propeller shank (figure 35).

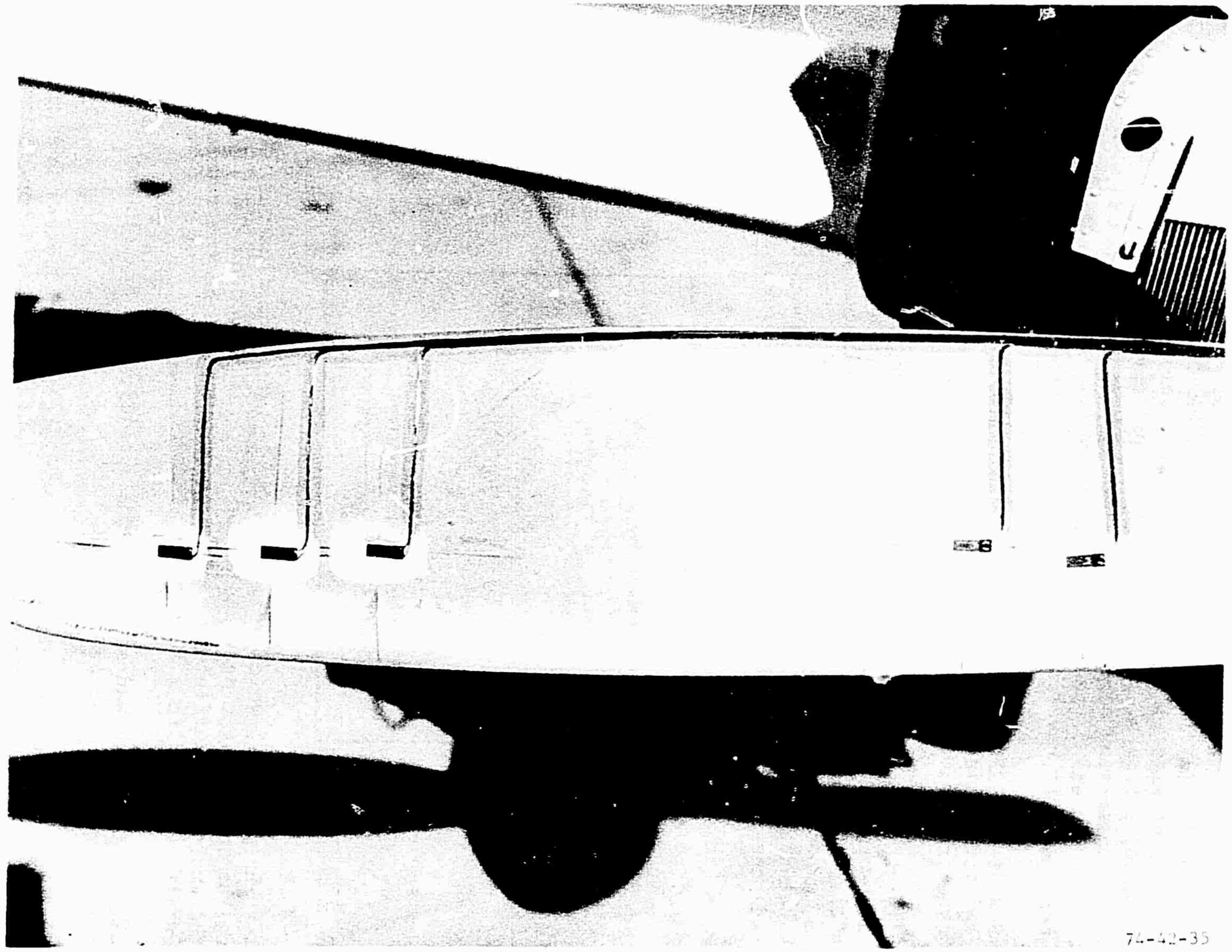


FIGURE 35. SENSOR WIRE ROUTING INSTALLED ON PROPELLER BLADE

The wire selected for use is a solid copper wire (Type 130-AWQ), high in electrical performance, with an extremely tough abrasion-resistant polyimide enamel insulation. The wire was carefully stripped for soldering, by mechanical means.

The procedure is to take the wire cut to length, leaving some excess. On one end of the wire, 1/32 of an inch of insulation is removed by scraping with a scalpel. Care is taken not to cut into the wire itself, as this causes stress risers and eventual fatigue failures of the lead.

As the hair-like wire is being handled, care is taken not to kink or otherwise damage it. The stripped end of wire and the iron are brought to the solder to "tin" the end of the conductor. After this is done, the lead can then be taken and soldered to the first gage terminal.

Since there are three wires attached to each gage and 16 gages per propeller, and all the leads look exactly alike, the only way to identify the individual leads is by knowing the exact terminal points they are connected to. Therefore, number one terminal is on the outboard gage closest to the trailing edge of the propeller on the camber side of number one blade. This terminal had a minus (-) polarity designation.

The second gage terminal must have two leads attached. This is accomplished with a wire that is cut twice as long as necessary, after which the center is found, scraped clean, and then is bent in a tight radius, using a rounded tool point, such as is found on the dental probe.

The wire is tinned at this bend and then soldered to the terminal. A thorough cleaning is given to remove any solder flux, and then a four-power glass inspection is required to be certain of a good connection. These leads are tacked in place designating the center lead plus (+) and the other lead zero (0).

These three leads are routed along the trailing edge to the propeller shank. The remaining gage leads follow the same route in succession such that all adjacent wires are in intimate contact. At no time is any wire crossed over another.

Bondable terminal strips, such as Micro Measurements Type CEG-25C, are attached to the blade shank with the gage leads soldered to them. The terminal backs themselves are swabbed with a cotton-tipped applicator lightly dampened in neutralizer. After the terminals are applied, all terminals are tinned and soldered. The strain gage leads are cut to length, stripped, tinned, and soldered to the terminals.

A second type of wire is required to connect from the terminal on the shank to the propeller hub itself. This wire is stranded, silver-plated copper with a teflon insulation (type 130-FWT). It is lightweight and flexible allowing the bundle to bridge the gap, in free air, from the controllable-pitch propeller blades to the hub itself.

The 130-FWT wire is stripped mechanically or with a thermal stripper. Approximately 1/16 of an inch of insulation is removed without breaking any strands, it is tinned and soldered to the terminal using the same technique as before.

When all leads are securely attached, cleaned, and examined with the four-power glass, they are encased as a bundle in the smallest heat shrink "spaghetti" tubing that will fit. The bundle of wire, where it comes together and initially enters the spaghetti, is securely lashed to the shank using a flat nylon lacing cord and a curved needle.

Adel clamps, manufactured by Heyman Manufacturing, Kenilworth, N.J., are used to secure the bundle to the hub. Enough slack is left, between the point at which the bundle is lashed and the point where it is clamped, so the freespan is streamlined with the direction of propeller rotation while the propeller is against the "increase" r/min stops. The propeller is exercised to "decrease" r/min and "full feather" position to ascertain freedom of movement and noninterference of the propeller and harness freespan.

The bundle is then routed and terminated to the propeller-mounted equipment.

Consideration is given, at all points along the harness routing, to the extreme centrifugal forces that will be imposed on the wire and the attendant attaching points.

Where the bundle is secured by clamps, it has to be lashed to the clamps by lacing cord to prevent it from pulling out in flight. The bundle is not allowed to "flap around" anywhere.

Consideration is also given to the balance and operation of the propeller during the installation. The installation has to be light and unrestrictive to the propeller operation and yet be sound enough to withstand the rigorous environment to which it is exposed to during flight.

All connections have to be perfect physically. No slack is allowed in the bundle, and the freespan is just enough for the propeller to be exercised throughout its range without chaffing, binding, or kinking.

A continuity check of the entire hookup, thus far, has to be conducted to ascertain that everything is correctly accomplished.

When it is ascertained at the final inspection that everything is correctly installed, the procedure is to mix, according to formula, the Scotch Cast No. 8 electrical resin. This protective coating is ready for use approximately a half hour after mixing. The resin is applied with a small acid brush, as a wet, even coat over the entire system. The gages and gage areas are covered. All the hookup wires, the terminals, and some of the lashed-up areas are coated.

Pliobond or Bostic adhesive is applied to the other lashings on the Adel clamps. This adhesive will "lock" the harness and insure security.

The Scotch Cast requires 24 hours to cure, but curing can be speeded up by applying heat. This is done by placing small electric baseboard-type heaters under each propeller blade. The thermostat is set for low heat and left on overnight. With heat, the Scotch Cast will "run" just before it starts to set. Several inspections are made for this condition so that runs can be removed while the adhesive is still in an uncured state.

On the second day, runs or other imperfections are repaired. A light finish coating of Scotch Cast is applied and heat is reapplied. With this second very thin coat (which is not mandatory), and applied heat, the Scotch Cast will "feather" at all edges. The Scotch Cast should overlap the wire leads by approximately 3/8 to 1/2 inch.

The specimen is then ready to be connected to an appropriate measurement system.

LOCATION OF STRAIN GAGES.

Those propeller blade operating stresses which are of significance in producing failures are the vibratory stresses (which are superimposed), the steady stresses, and the shear stresses.

The maximum vibratory bending stresses occur at the nodal points during vibration at the various natural frequencies of the propeller. There are an infinite number of natural frequencies of a beam-like structure, such as a propeller, but, fortunately, only in the first two or three flapping modes is the propeller excited to amplitudes sufficient to produce fatigue failure. These flapping modes can be either symmetrical, in which the hub has no lateral movement, or nonsymmetrical, in which the blades vibrate out of place with each other in the case of a two-bladed propeller.

The most positive way to locate the nodal points in the various modes of vibration is to mount the propeller on a shaker table or attach a vibration excitor to a suspended propeller and observe the creation of various modes as the frequency of the excitor is varied. Both the natural frequencies and node locations will change with rotation of the propeller, but these are small and predictable changes. During these static shaker tests, any looseness in the blade retention bearings is taken up to prevent attenuation of the excitation.

Location of the strain gages to measure the maximum steady stresses produced principally by the constant centrifugal and aerodynamic forces on the blades lends itself to prediction by calculation.

A similar approach is used to predict the blade locations which are subjected to the highest shear stress.

Strain gages are mounted at various locations around the shank of the blades since failure at this critical location is most catastrophic. It is considered advisable to locate at least two gages at the shank area, one at the leading edge (with respect to a reference radius), and one at the maximum camber side.

It will be found that the measurement of peak vibratory stresses for the tip and mid-blade area is very sensitive to location of the sensor. If the strain gage is not located precisely at the particular nodes created during the various vibration natural frequencies, the highest stresses may easily be overlooked. Similarly, the shank stresses, especially the attenuating stresses, vary appreciably around the shank.

As a first approximation, values such as shown in table 1, under section FAA/HSD Slipringless System, may be derived by calculation. A static vibration survey of the propeller for the purpose of locating the significant stress regions, however, is considered a prerequisite to any scientific flight test program.

TYPICAL FLIGHT TEST PROFILE

An aircraft's propeller stress history, which is obtainable with the data systems described earlier, will normally be a complex combination of steady and vibratory loading. It may be possible for the blade material to accumulate both high- and low-cycle fatigue damage. Figure 36 illustrates a typical propeller blade stress flight profile. Low-cycle fatigue may be encountered due to maneuver loading and ground-flight-ground cycles, and high-cycle fatigue will be caused by the blades vibrating in resonant modes.

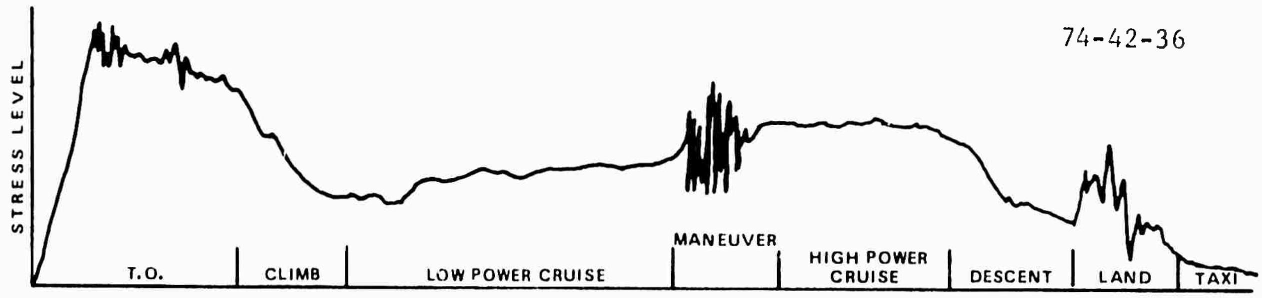


FIGURE 36. TYPICAL FLIGHT PROFILE--PROPELLER BLADE STRESS

New flight test programs must be tailored to reflect the service to which the aircraft will be subjected. An analysis should be made at the onset to forecast the service life history of the aircraft, and the flight test program should be designed accordingly, bearing in mind that the flight test itself is a small sample of the service life to be encountered.

A representative flight test, as used on a PA31 aircraft, is presented here as an aid to devising a plan more suited to the particular aircraft under test. This profile represents only a small sampling of the actual service life of the propeller.

OBJECTIVE.

The objective of these flight tests was to measure, identify, and evaluate vibratory and steady propeller stresses which may cause damage leading to eventual failure, and which may be:

1. Inherent in the characteristics of the engine-propeller combination.

2. Due to tolerance spread between like models.

3. The result of service operation, aging, etc.

4. The result of inadvertently exceeding the recommended operating limits.

TEST VEHICLES.

Three model PA31 Piper Navajo aircraft having TIO-540-AIA turbo-supercharged engines and Hartzell Model HC-E2Y (K, R) - 2B/C8475-4 two-bladed propellers, with approximately 300, 600, and 900 hours since new or major engine-propeller overhaul, respectively, were used for this flight-test phase.

INSTRUMENTATION.

1. Propeller. Each propeller was instrumented with 16 self-temperature-compensated, 350 ohm, foil strain gages as follows:

a. Blade 1.
87.5 Percent Radius, Camber Side, Bending
82.5 Percent Radius, Camber Side, Bending
77.5 Percent Radius, Camber Side, Bending
50.0 Percent Radius, Camber Side, Bending
45.0 Percent Radius, Camber Side, Bending
Shank Leading Edge, Bending
Shank Face, Bending
Shank Camber Side, Bending

b. Blade 2.
85 Percent Radius, Camber Side, Bending
80 Percent Radius, Camber Side, Bending
75 Percent Radius, Camber Side, Bending
50 Percent Radius, Camber Side, Bending
50 Percent Radius, Face Side, Bending
20 Percent Radius, Camber Side, Bending
Shank Leading Edge, Bending
Shank Face, Bending

Note: Blade 1 Radius 40.125 inches
Blade 2 Radius 39.9375 inches

2. Propeller and Engine.

a. The FAA/HSD self-powered, slipringless blade vibration measurement system was installed on the right-hand engine.

b. A sensor at the No. 1 cylinder ignition lead was used to mark the firing sequence.

c. A once-per-revolution magnetic pickup was installed as part of the blade vibration measurement system (Electro Products Type 3055A).

d. A suitable accelerometer was installed on each of the three major axes of the engine at the No. 1 cylinder. Three leads were brought to the cabin area for recording on magnetic tape.

3. Aircraft Flight Parameters.

a. Sensors were installed for the following:

(1) Vertical Acceleration - Edcliff Model 7-114 potentiometer type, -1.0 to +2.5g, 1,000 ohms.

(2) Airspeed - Computer Instruments Corporation Model 7100 potentiometer transducer, zero to 250 knots, 1,000 ohms.

(3) Altitude - CIC Model 7000, 1,000 ohms, zero to 30,000 feet.

(4) Manifold Pressure - CIC Model 6100, 1,000 ohms, 10" Hg Abs. to 43" Hg Abs.

(5) Deck Angle - Edcliff Model 5-510 Inclinometer, ±45°, 1,000 ohms.

(6) Landing Gear Position - Single pole, double throw switch and relay.

4. Data were recorded per IRIG seven-track standard at 15 inches per second (in/s) as follows:

a. Track 1: Audio, Direct Record
b. Track 2: Data Multiplex 1, Direct Record
c. Track 3: Data Multiplex 2, Direct Record
d. Track 4: Data Multiplex 3, Direct Record
e. Track 5: Data Multiplex 4, Direct Record
f. Track 6: IP Pickup, FM Record
g. Track 7: Accelerometer Input, FM Record

5. On-Board Equipment. The following equipment was mounted in the cabin area, accessible to operating personnel:

a. Data System Translator Unit.
b. Airborne Instrumentation Seven-Track Magnetic Tape Recorder.

FLIGHT TESTS.

1. All flight tests were accomplished with the aircraft loaded to gross weight at takeoff. Data records were made for 45 seconds at each setting. All altitudes are indicated altitudes. Mixture was at maximum power setting for all conditions.

Note: 1. Flight flight tests were programmed to avoid the carryover of a run on a new tape. Ground calibration signals were recorded at the beginning of the first tape for each flight. Also, post-flight calibrations were recorded on the last tape, if space and time permitted.

2. Description of each test setting by voice annotation and on lap record.

3. The lap record included date, pilot, observer, technician, time out, time in, weather, temperature, altimeter setting, test description, tape number, and calibration--yes or no.

2. Schedule (sequenced as convenient).

a. Takeoff and climb at best angle-of-climb to 2,000 feet.

(1) Throttle : Full

(2) Horsepower : 310

(3) Airspeed : 90 mi/h (best angle-of-climb)

(4) Data Recording : Continuous

b. Constant manifold pressure, variable r/min, level flight 2,000 feet.

(1) Full throttle, 2575 to 2375 r/min, 25 r/min increments

(2) 38.0 in Hg MAP - 2575 to 2375 r/min, 25 r/min increments

(3) 37.0 in Hg MAP - 2575 to 2300 r/min, 25 r/min increments

(4) 31.0 in Hg MAP - 2575 to 1900 r/min, 25 r/min increments

c. Static at maximum power from maximum r/min to 2050 r/min at 50 r/min increments.

d. Level flight at 10,000 feet mean sea level (m.s.l.) with maximum power from 2675 r/min to 1975 r/min at 25 r/min increments.

e. Level flight at 14,000 feet m.s.l. with maximum power from 2675 r/min to 2300 r/min at 25 r/min increments.

f. Level flight at 14,000 feet m.s.l. with 65 percent power from 2675 r/min to 1975 r/min at 25 r/min increments.

g. Timed climb from 10,000 feet m.s.l. to 13,500 feet m.s.l. with maximum power from 2675 r/min to 2325 r/min at 25 r/min increments.

h. Asymmetrical level flight, 2000 feet, *r/min low pitch: +6° to -6° in 1° increments. Repeat -6° to +6°.

i. Variable airspeed, 2000 feet, *r/min, low pitch maximum airspeed to minimum controllable airspeed in 10-knot (approximate) increments.

Note: *r/min was advised. These were resonant speeds as determined in 2.b.

j. Repeated i; with full flaps and gear down, from maximum flap operation speed to minimum controllable airspeed in 10-knot (approximate) increments.

k. Ground runs, 0°, 45°, 60°, 90°, etc. with respect to wind direction (at least 10 knots). Idled to full throttle and returned in one minute, each position.

SUMMARY

Instrumentation required to conduct an in-flight propeller stress survey can be as sophisticated and effective as resources allow. The older systems, satisfactory at their times of inception, do not offer the quality, versatility, or utility inherent with contemporary equipment. Modern systems can be tailored to each application and achieve results limited only to the extent of the users' imagination. Selection and installation of the strain gages, the attendent wiring, and protective coatings are cardinal factors in determining success or failure--no matter which system is employed. The strain gage installation must be properly accomplished in order for the rest of the system to provide meaningful data.

With a long- or short-term strain gage installation, one may select any combination of components, as shown in figure 10, to comprise a data collection, recording, and processing system. Referring to figure 10, observe that the simplest system and probably the least expensive in terms of equipment and ease of installation is the frequency modulation (FM) transmitter-receiver oscillographic recorder system. The disadvantages of this system are in the small amount of data that can be collected and the tedious task of manually processing it.

A "middle of the road" system could use the same FM transmitter-receiver, but connected to a magnetic tape recorder instead of an oscillograph. The FM transmitter-receivers are readily adaptable to most any engine-propeller combination. The use of electronic data processing equipment, as outlined on page 18, would now be the most advantageous option, even though the magnetic tape may still be used to drive an oscillograph for manual data reduction, if so desired.

The cost-effectiveness of this system (the degree of sophistication to be built-in via the use of electronic data processing equipment) is commensurate with "what" and "how big" the need to know is.

The Federal Aviation Administration/Hamilton Standard Division (FAA/HSD) coupling can be substituted for the FM transmitter-receiver, with the insertion of the discriminator package, to make the signal acceptable to electronic data reduction as aforementioned. However, this coupling is more difficult to adapt and install. The rotor is handcrafted, to an extent, and is somewhat irregular in shape. The rotation in extreme close proximity (a few thousands of an inch) within the stator plates, could cause rubbing or chaffing, which could destroy the signal and possibly the entire assembly.

The FM coupling provides one channel of strain data for each transmitter-receiver. The FAA/HSD capacitive coupling provides up to 16 channels. The FM system allows the option of keeping costs down to the specific number of strain gage channels required.

Whereas, the FAA/HSD system could be available by special order, the FM system is an "off-the-shelf" stock item. A failure in the FAA/HSD coupling would disable the entire system. With the FM system, a failure in one transmitter-receiver would not affect the others. Although the FAA/HSD system works very well over long period of time, installation difficulties tend to weigh against this in favor of an FM system.

Table 3 can be used as a quick cross-reference for system evaluation as to relative merit.

TABLE 3. SYSTEM EVALUATION CROSS REFERENCE

System	Relative Cost of Coupling	Long-Term Reliability Capability	Adaptability And Ease of Installation	Electronic Data Processing	System Availability	Overall Cost Effectiveness
Sliprings and Brushes	Inexpensive	No	Fair	Very Poor	Poor	Poor
FM Transceiver	Moderate	Yes	Good	Excellent	Excellent	Excellent
Capacitive Coupling	Costliest	Yes	Poor	Excellent	Fair	Fair

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